The Mississippian Lime: Kinematics of a Play—
Structure, Reservoir Characterization and Production Performance of the Horizontal Mississippian Play*

Shane Matson[1]

Search and Discovery Article #110184 (2015)**
Posted June 29, 2015

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Editor's note: Please refer to related article by the author: "Mississippi Lime Play: From Outcrop to Subsurface – The Evolution of a Play, Search and Discovery Article #110170 (2013).

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Abstract

The Mississippian section of the Mid-Continent has been an exploration target for the oil and gas industry for 90 years. Hydrocarbons have been economically produced from thousands of vertical wells targeting multiple productive facies with log porosity values ranging from 2% to 48%. In 2003, Tulsa-based Ceja Corporation initiated drilling program utilizing horizontal drilling to exploit seismically identified high porosity (>35%) Mississippian tripolite. Through 2009 more than 20 horizontal wells were successfully drilled and completed, setting in motion the hugely extensive Mississippi Lime Play of the Mid-Continent. In 2009 Spyglass Energy Group drilled the Shaw 1A-8H, one of the earliest horizontal well east of the Nemaha Ridge targeting the low porosity (2-6%) Mississippian; the results of which set in motion the assembling of one of the largest acreage positions in the play. Spyglass Energy Group, led by explorationist Charles Wickstrom, has been at the forefront in pioneering the play, taking it from arm-waving to visualization to exploration to full exploitation.

The Mississippi Lime Play is unique in the spectrum of newly defined "Unconventional Reservoirs" in that it encompasses multiple reservoirs of highly varying petrophysical parameters which are commonly stacked or laterally adjacent to one another.

This leads to many misunderstandings of the section. The variability of the section, coupled with the high-fluid-volume production has led to yet another paradigm shift in how the industry interprets reservoir objectives in horizontal carbonate plays. Geologists utilizing fresh eyes on new data while rediscovering the monumental works published throughout the 1900s are on the cusp of cracking the many codes held tight in this dynamic geological section.

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AAPG Playmakers' Forum
January 24, 2013

Mississippi Lime: Kinematics of a Play

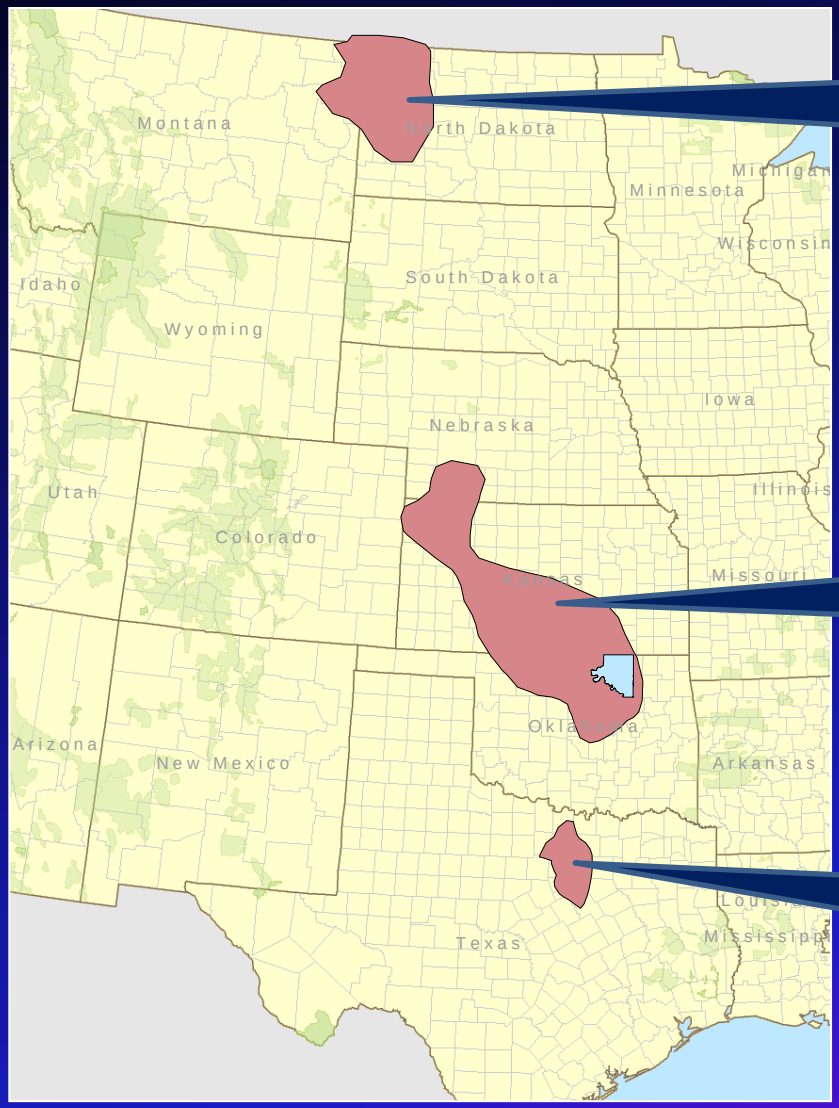
Structure, Reservoir Characterization and Production Performance of the Horizontal Mississippian Play

Shane E. Matson
Geologist
Spyglass Energy Group, LLC

Presentation

- Historical perspective
- Regional framework
- Key play elements
  - Trap dynamics
  - Infrastructure
  - Reservoir geology
  - Stimulation
  - Production results

The Mississippi Play is Huge



Elm Coulee Field
Bakken Formation
~5,000 producing wells
12 million acres

Mississippian Lime Play
Area of Leasing
~1,000 wells drilled
30 million acres

Newark East Field
Barnett Shale
~16,000 producing wells
3 million acres

Historical Perspective

A special problem that we have been dealing with in the last few years is the one where we are concerned about the variation in the fluid levels within what we identify as a single reservoir. What I am referring to is the fact that we can have the following fluid levels in a particular well –

Gas, Oil, Water;
Then just Oil;

Then just Gas and Water;
Then just Gas;

Then Oil , Water;
And then just Water;

then another zone back to Oil or Gas. We may not have this particular sequence in any one well, but we may have any kind of sequence such as this one.

Rick P. Clinton

Symposium of the Mississippian of Oklahoma and Kansas

TGS Digest, Volume 27, 1959

Historical Perspective

- Preliminary Report on the Lead and Zinc of Oklahoma – *OGS Bulletin 9, 1912*
- *Fauna of the So-Called Boone Chert, USGS Bulletin 595*
- The Oil and Gas of Geology of the Foraker Quadrangle, Osage County, OK, *USGS Bulletin 641-B, 1916*
- Structure and Oil and Gas Resources of the Osage Reservation, Oklahoma, *USGS Bulletin 686, 1922*
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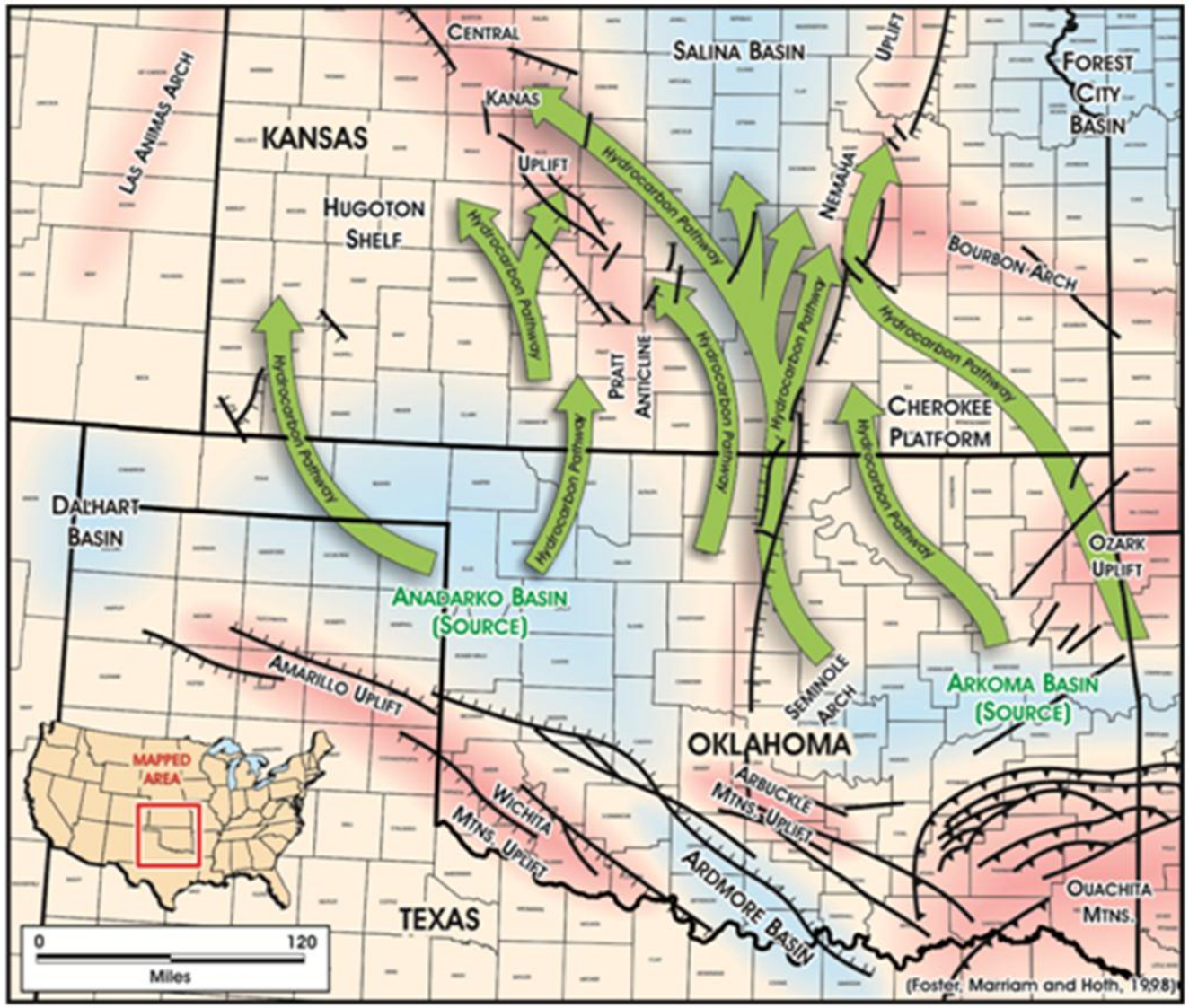
- *Hydrocarbon Accumulation in the "Meramec-Osage" (Mississippian) Rocks, Sooner Trend, Northwest Central Oklahoma, AAPG Bulletin v. 59, 1975*
- *Geology and Ore Deposits of the Picher Field Oklahoma and Kansas, Geological Survey Professional Paper 588, 1970*
- *Mississippian Trend Garfield, Major and Alfalfa Counties Oklahoma, The Western Company, 1965*

Mississippian Overview – Oil Migration and Distribution

The Woodford Shale was the source for much of the hydrocarbons produced in the Anadarko and Arkoma basins.

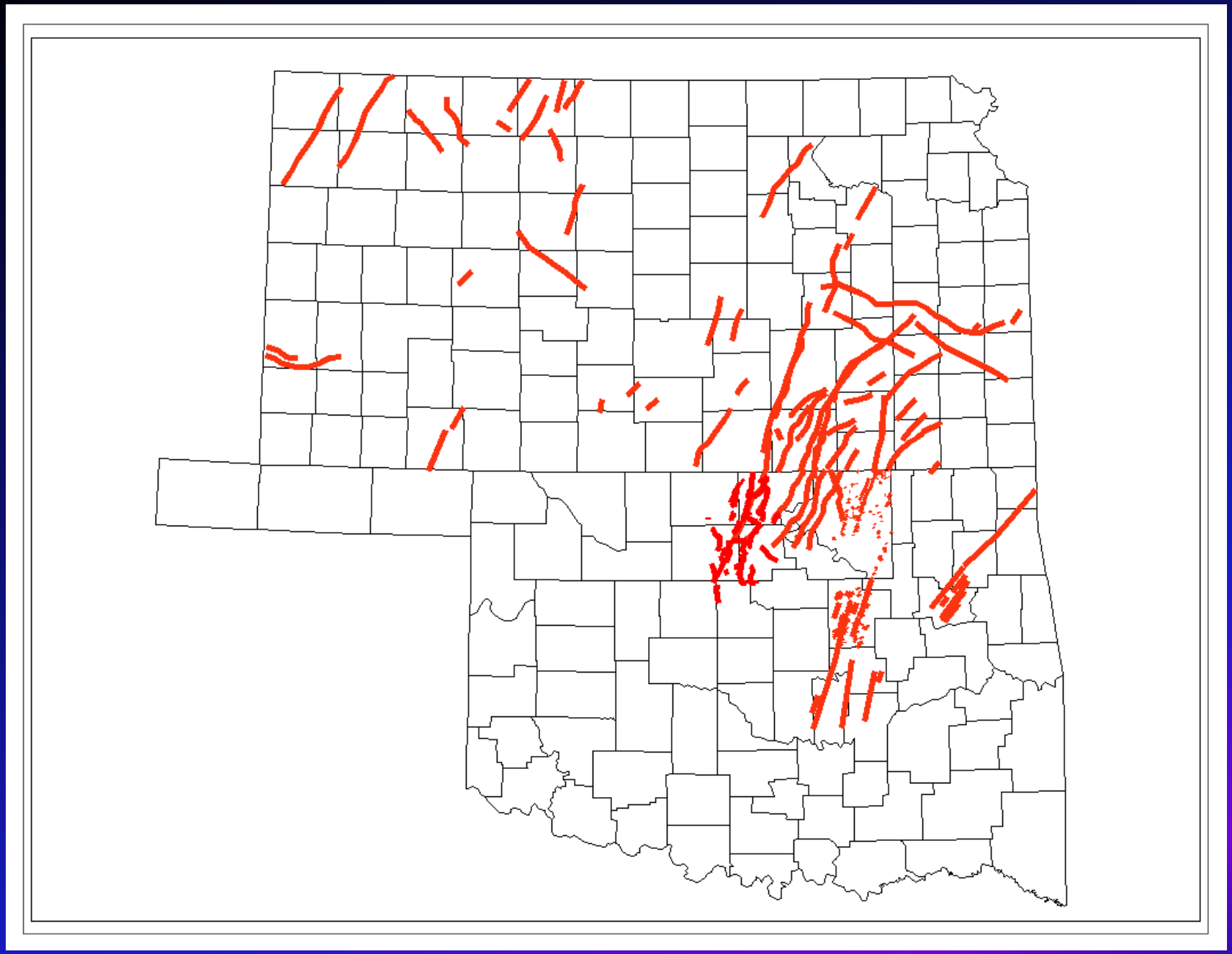
- The deep Anadarko basin produced gas-weighted hydrocarbons
- The Arkoma Basin was shallower and produced oil-weighted volumes

Woodford Shale - Migration Paths



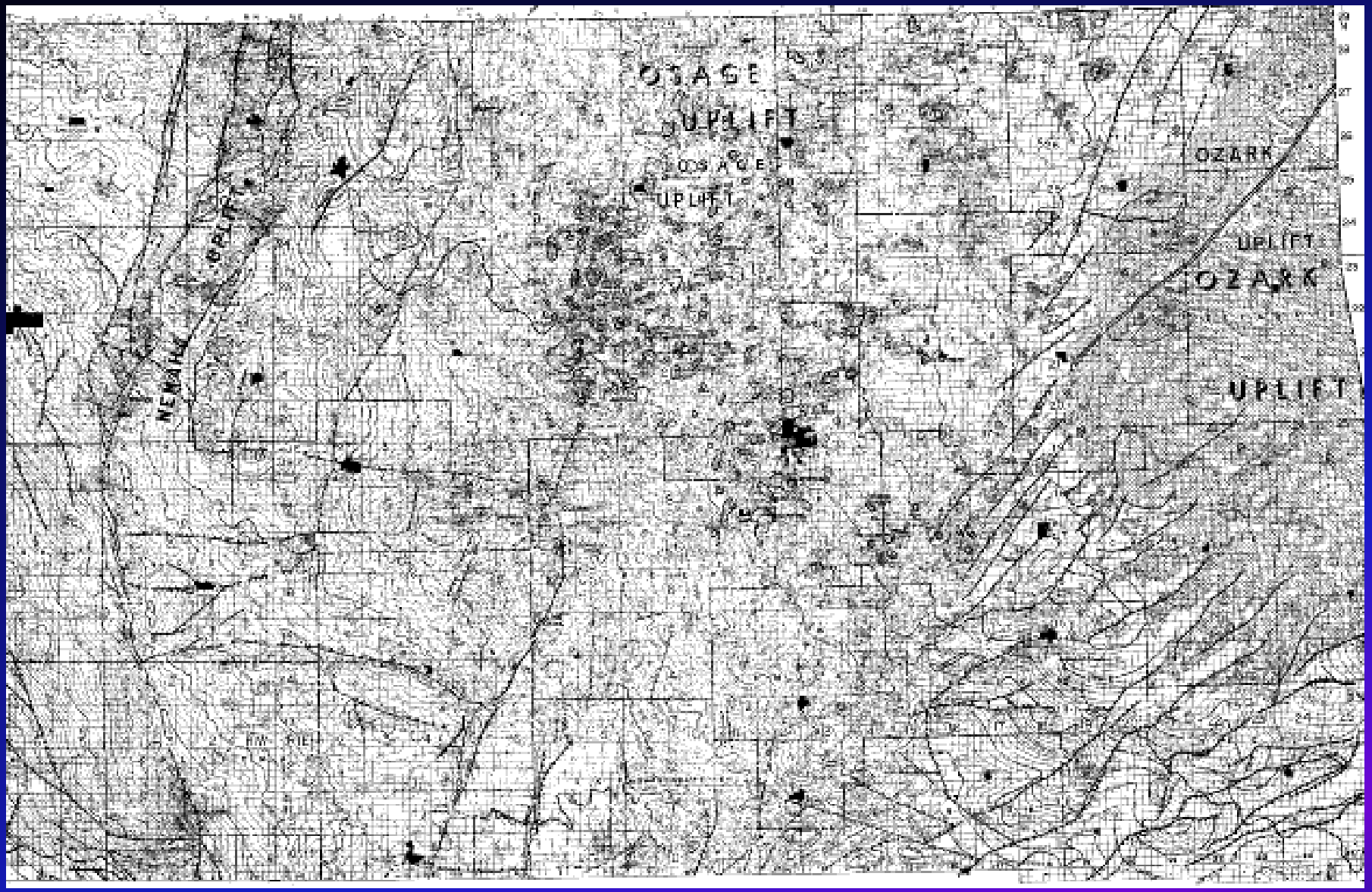
Modified from Gerhard, L. KGS Bull 250

Tectonic Lineaments – Surface and Subsurface

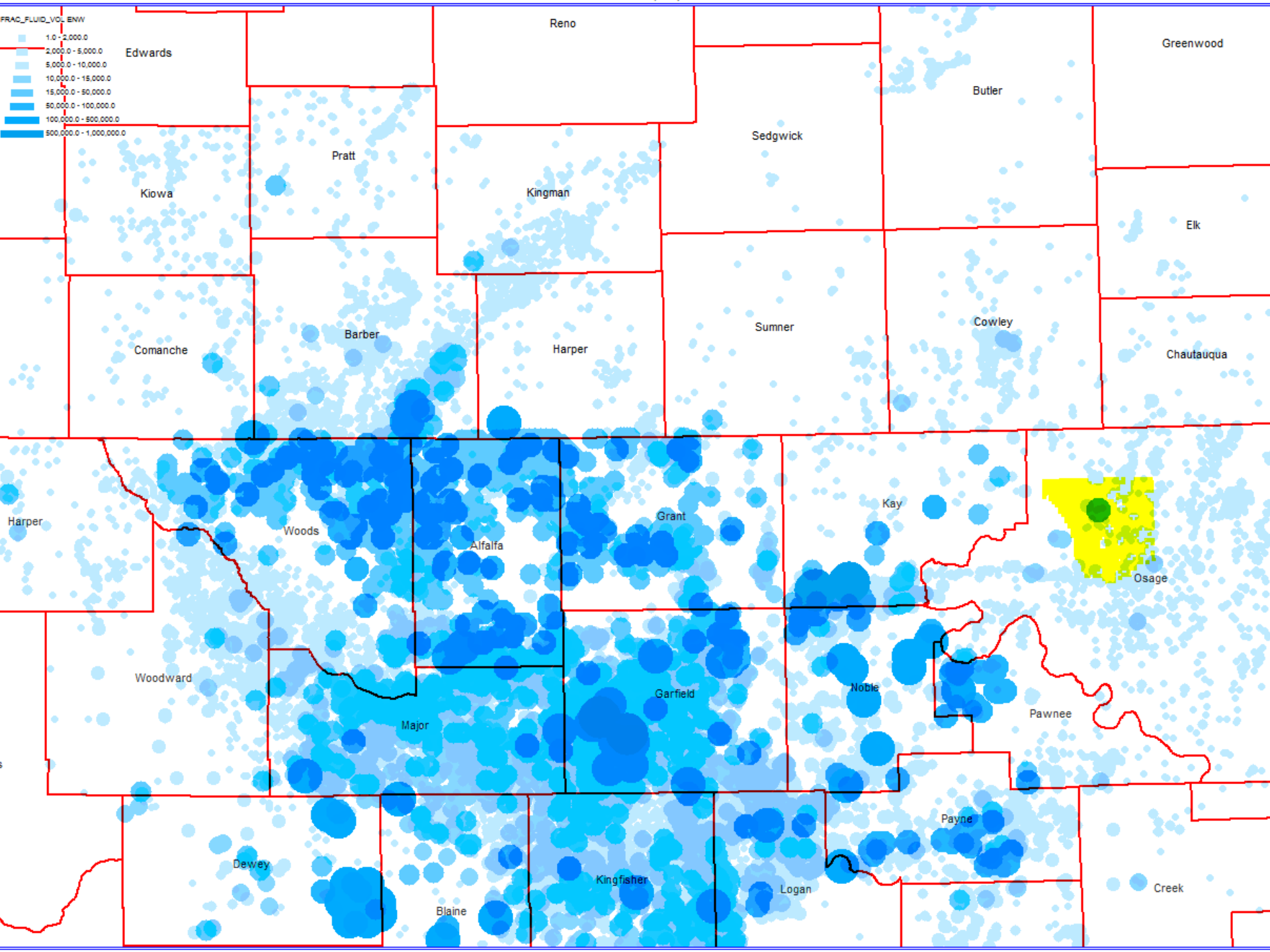


Multiple Sources – OGS Bulletin 40, KGS, Proprietary Magnetic and Shallow Surface

Arbuckle Structure – East of Nemaha Ridge



Gatewood 1970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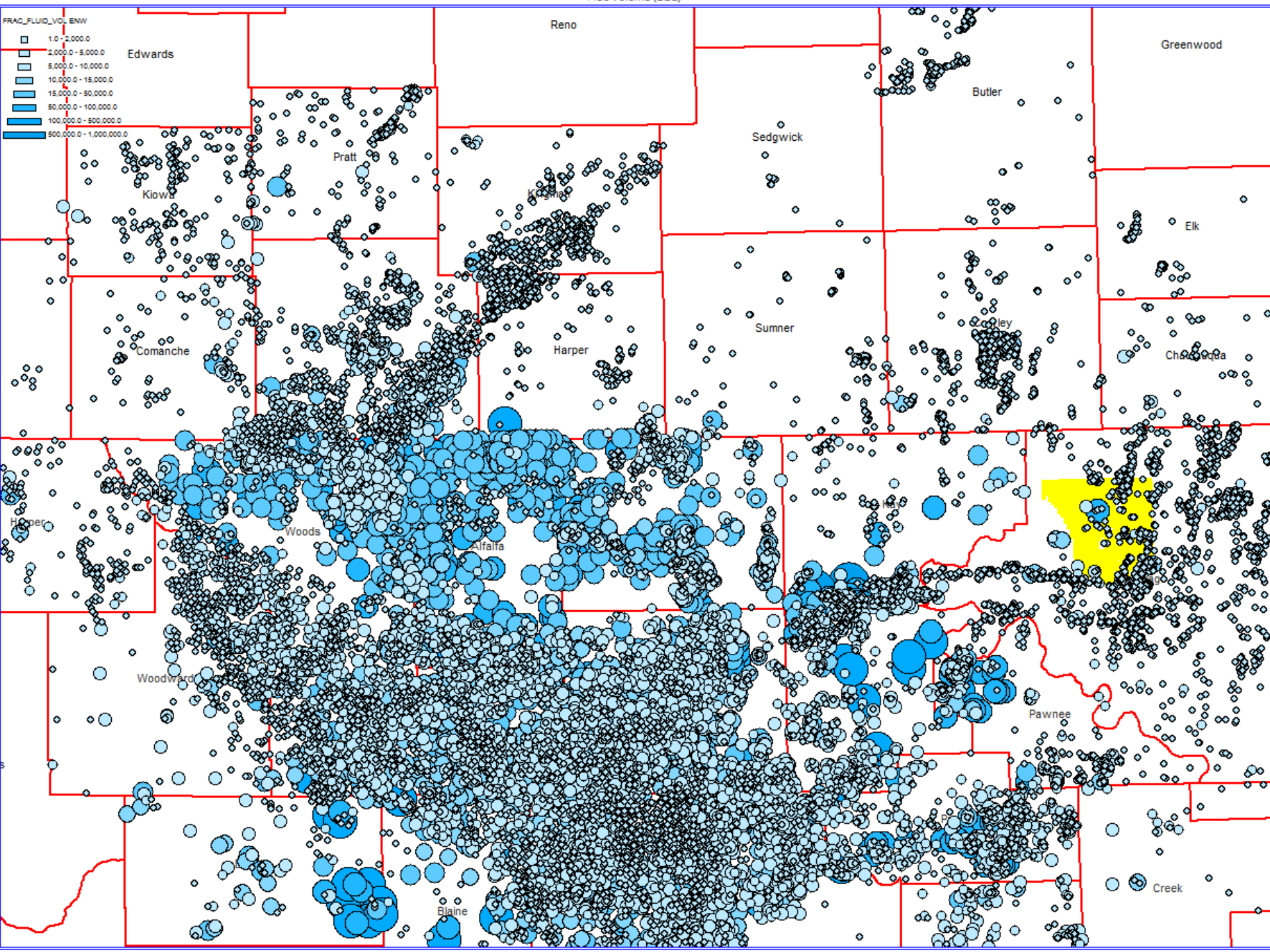
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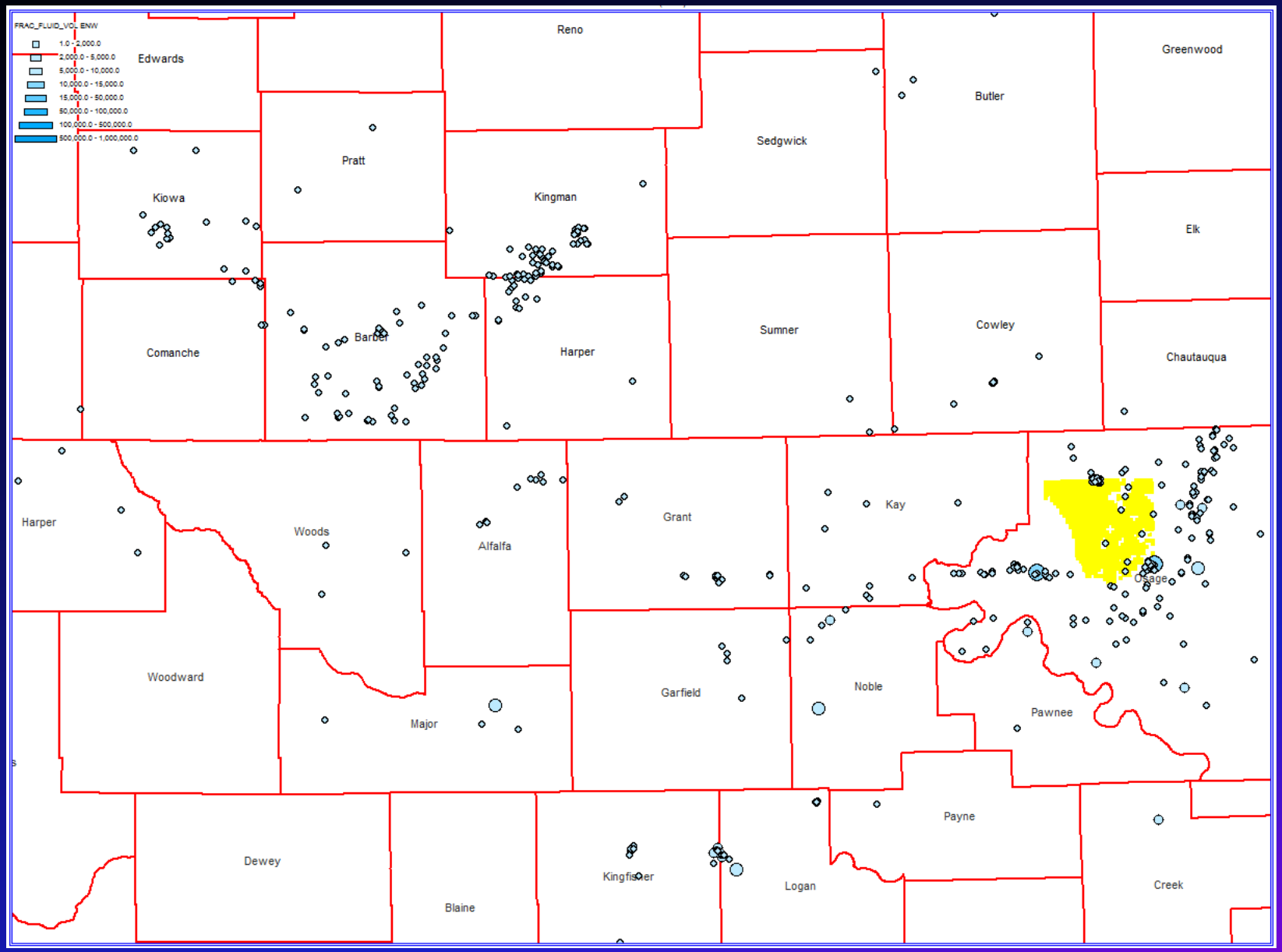
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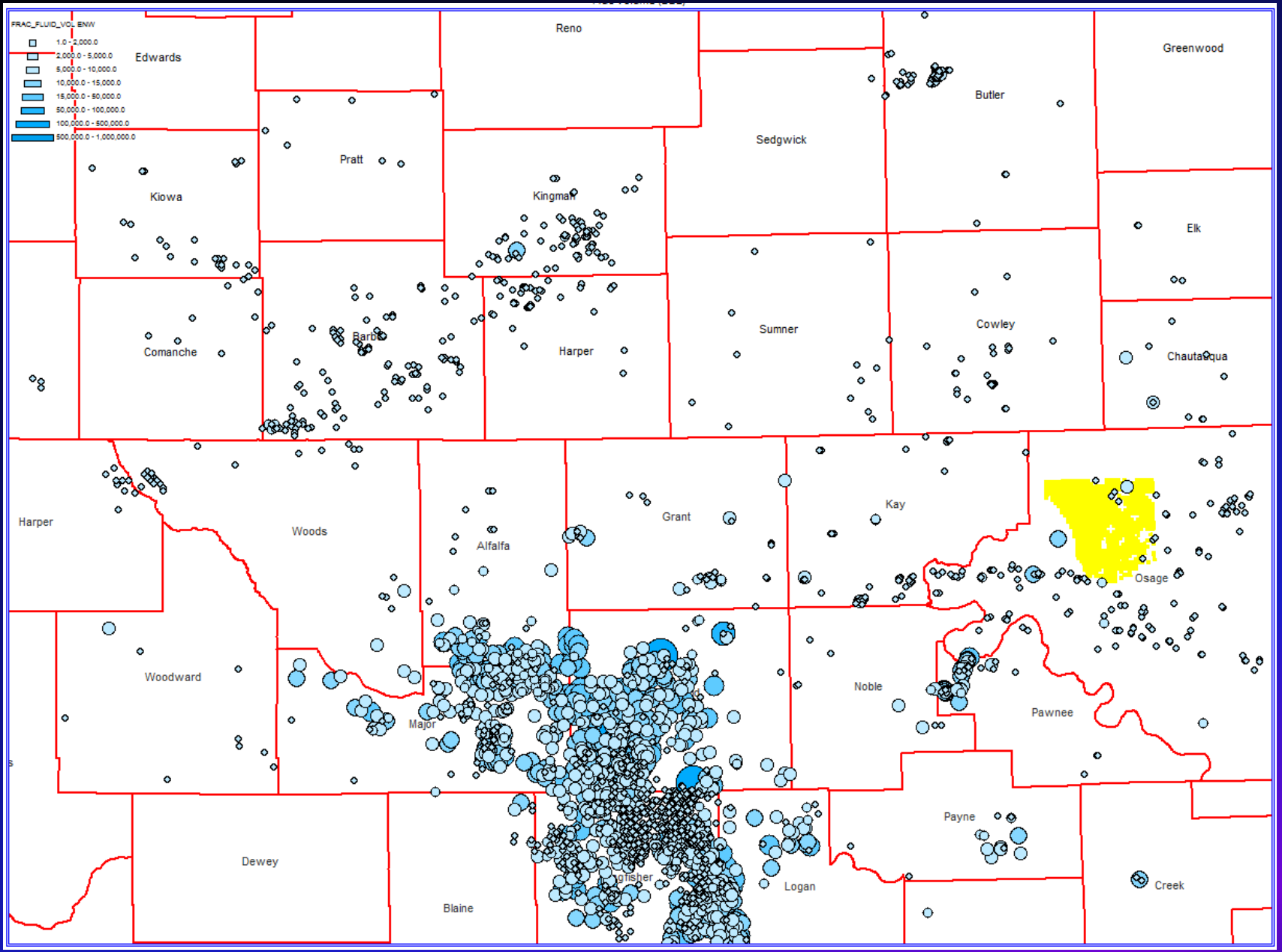
Pre-1960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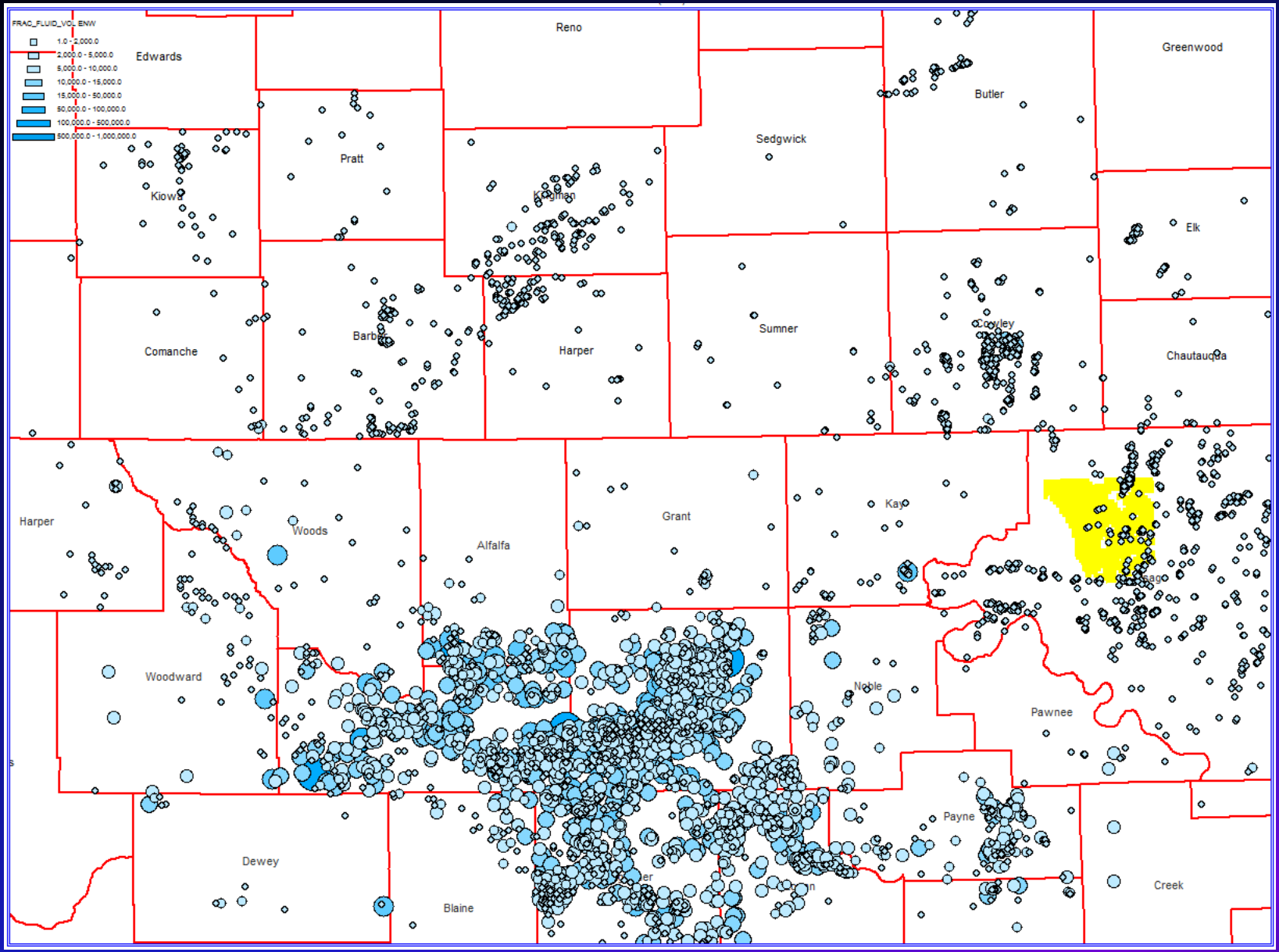
1960-1970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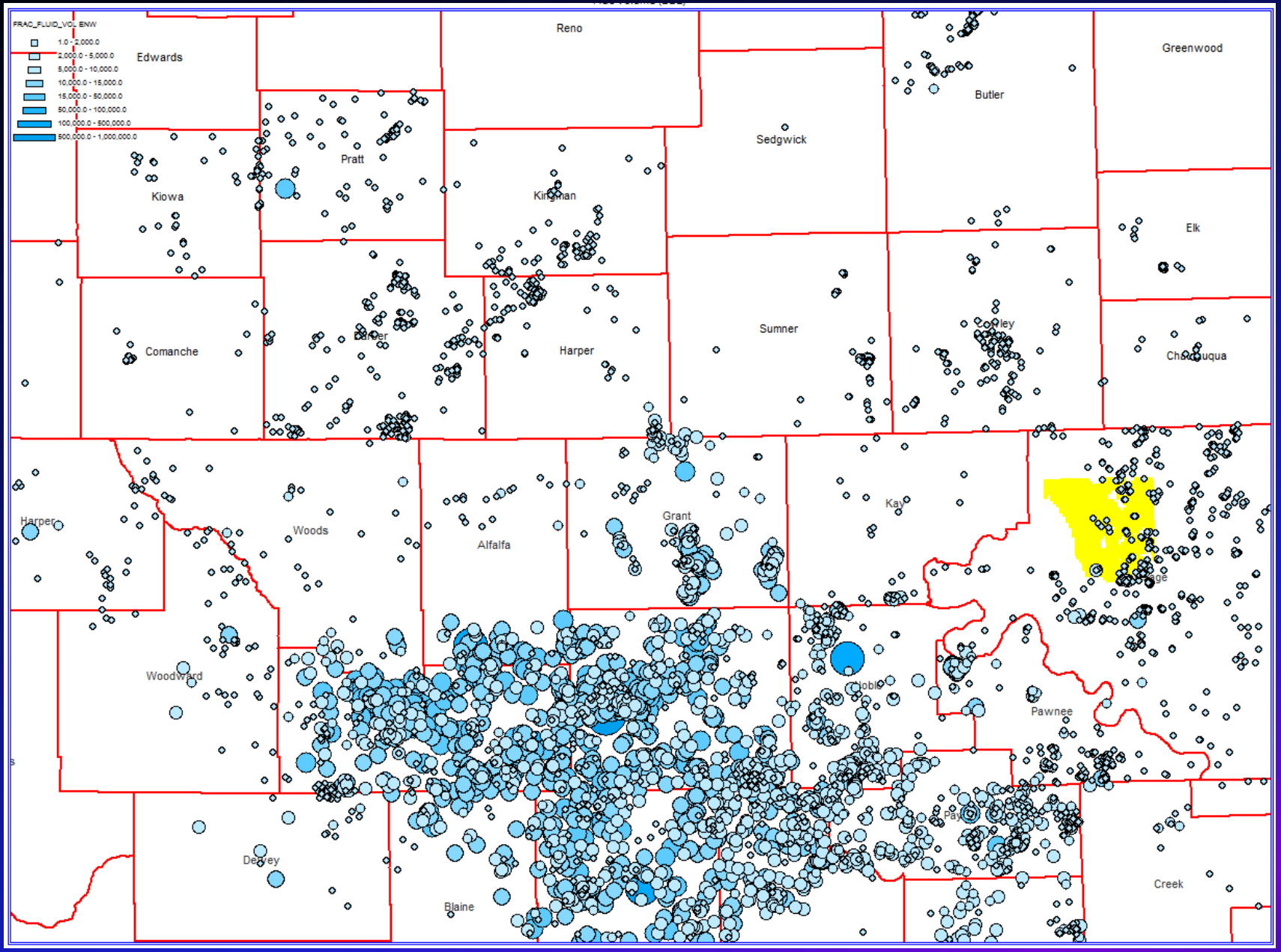
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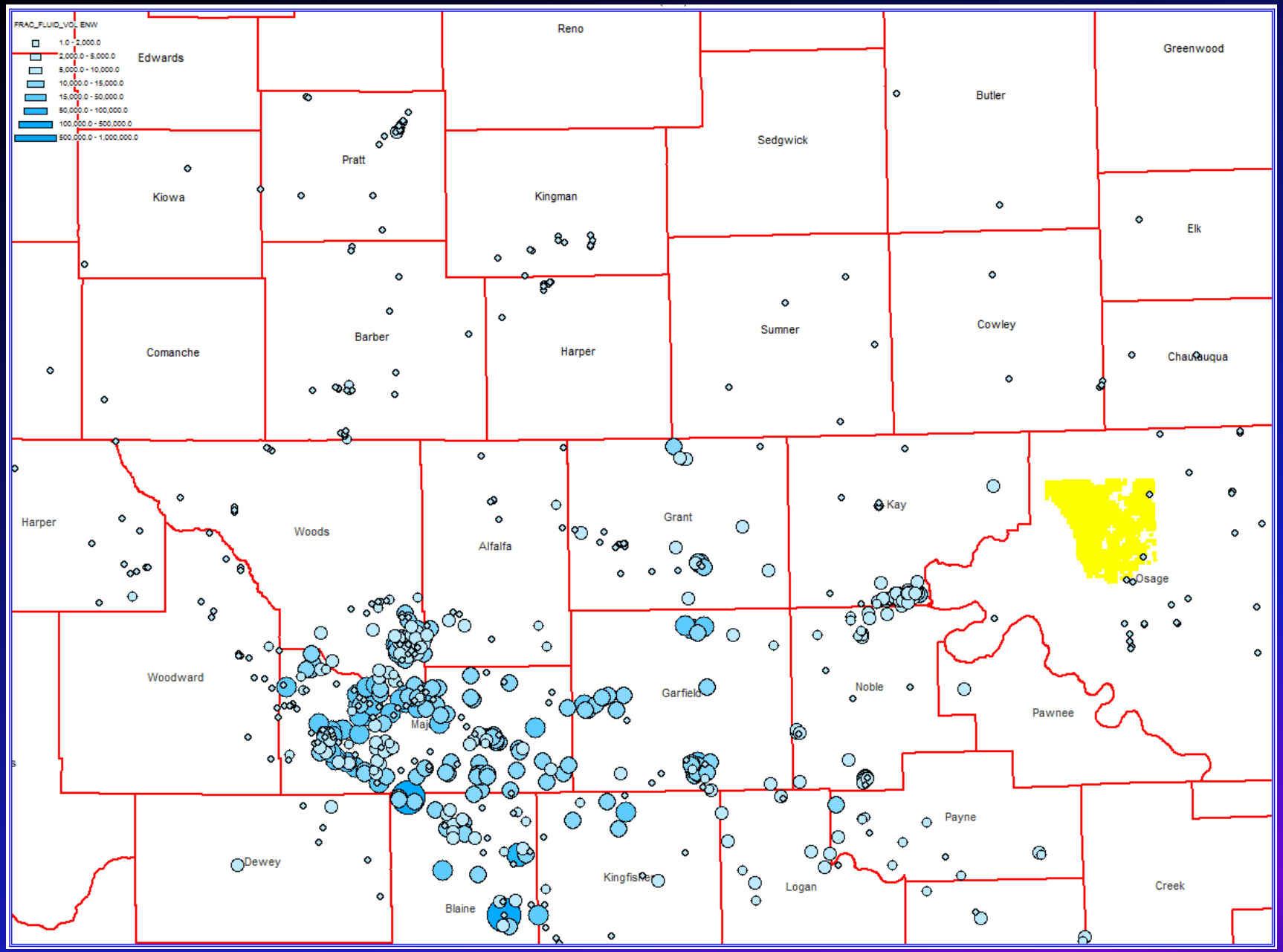
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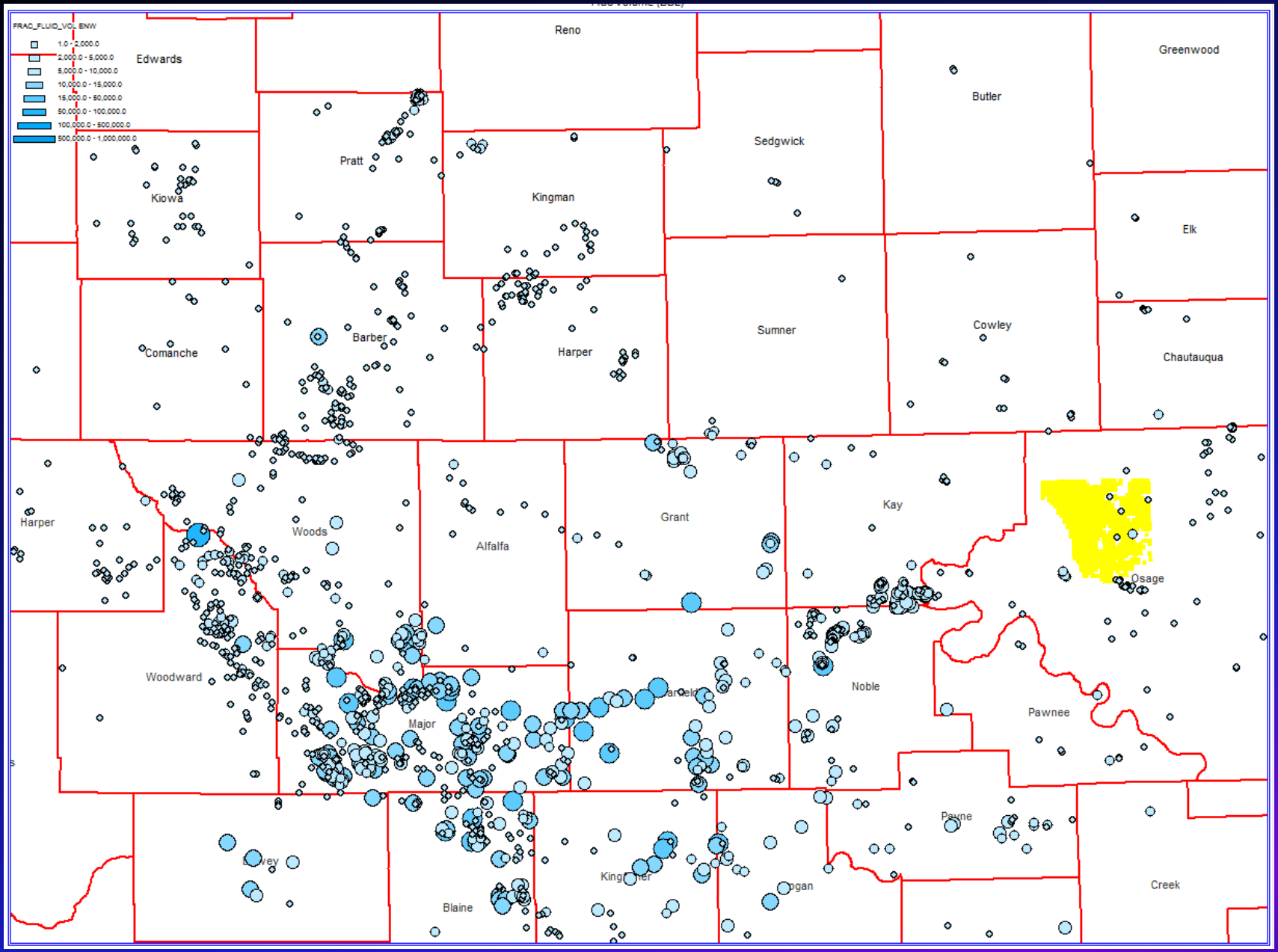
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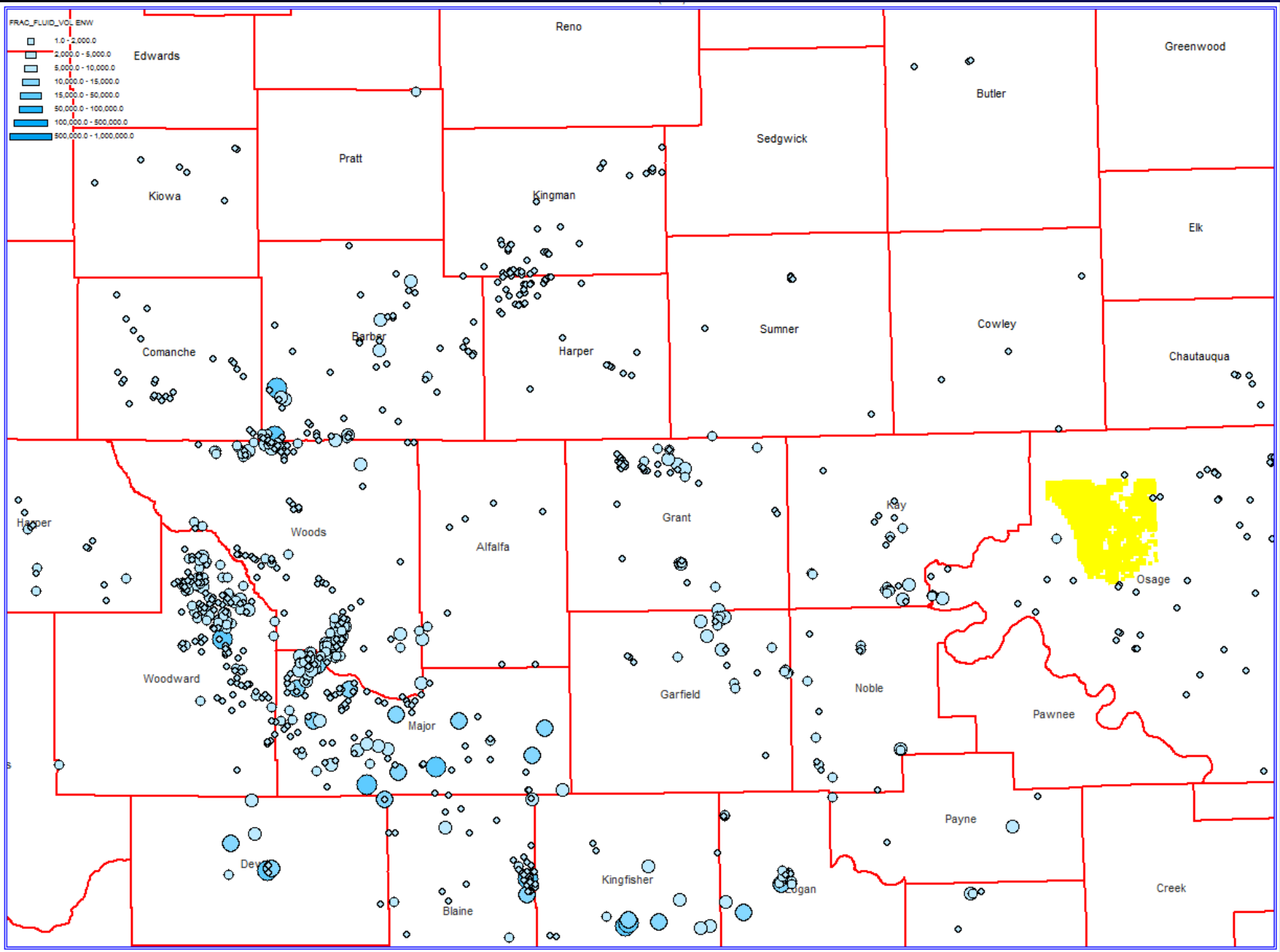
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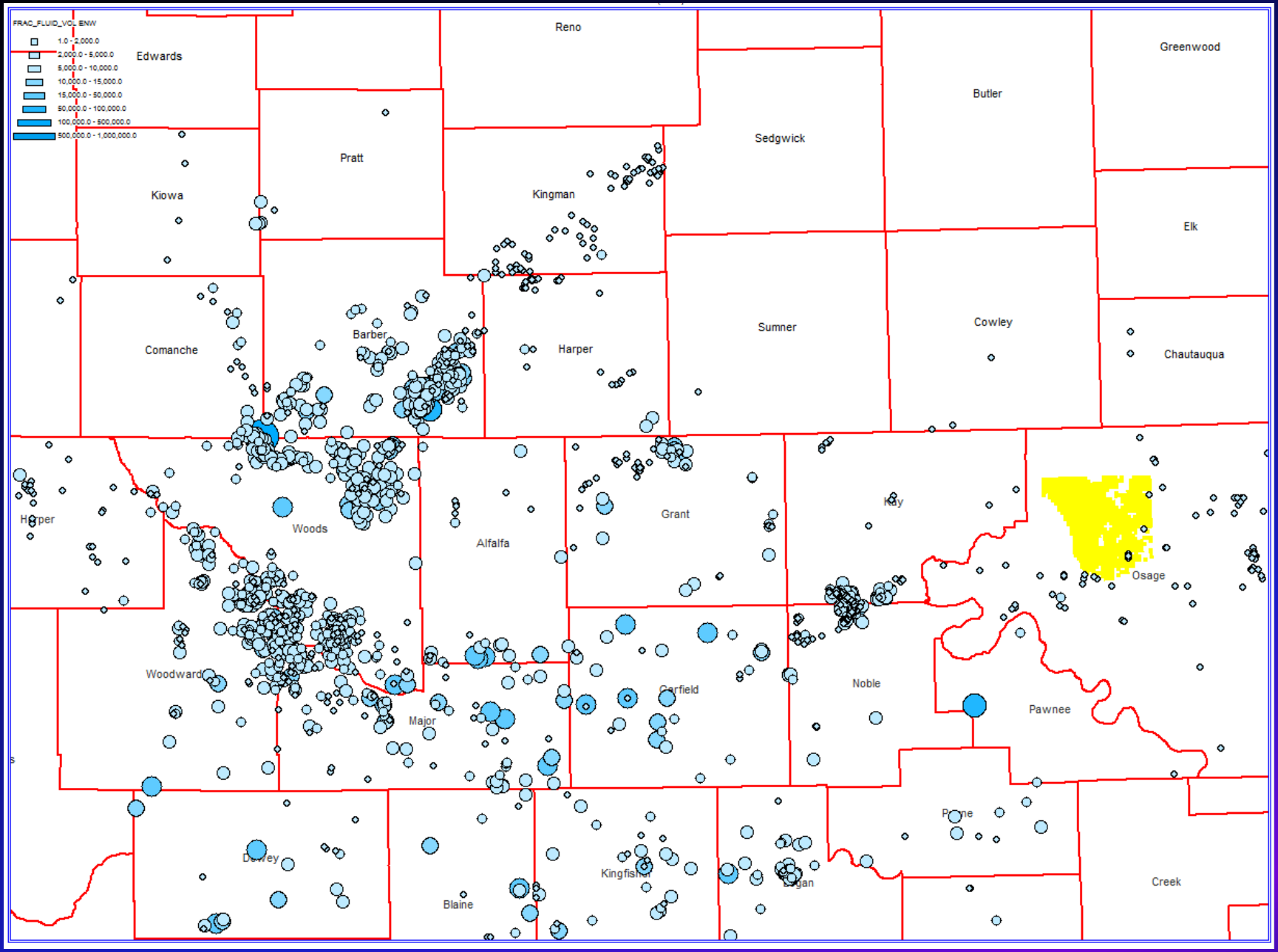
2000-2005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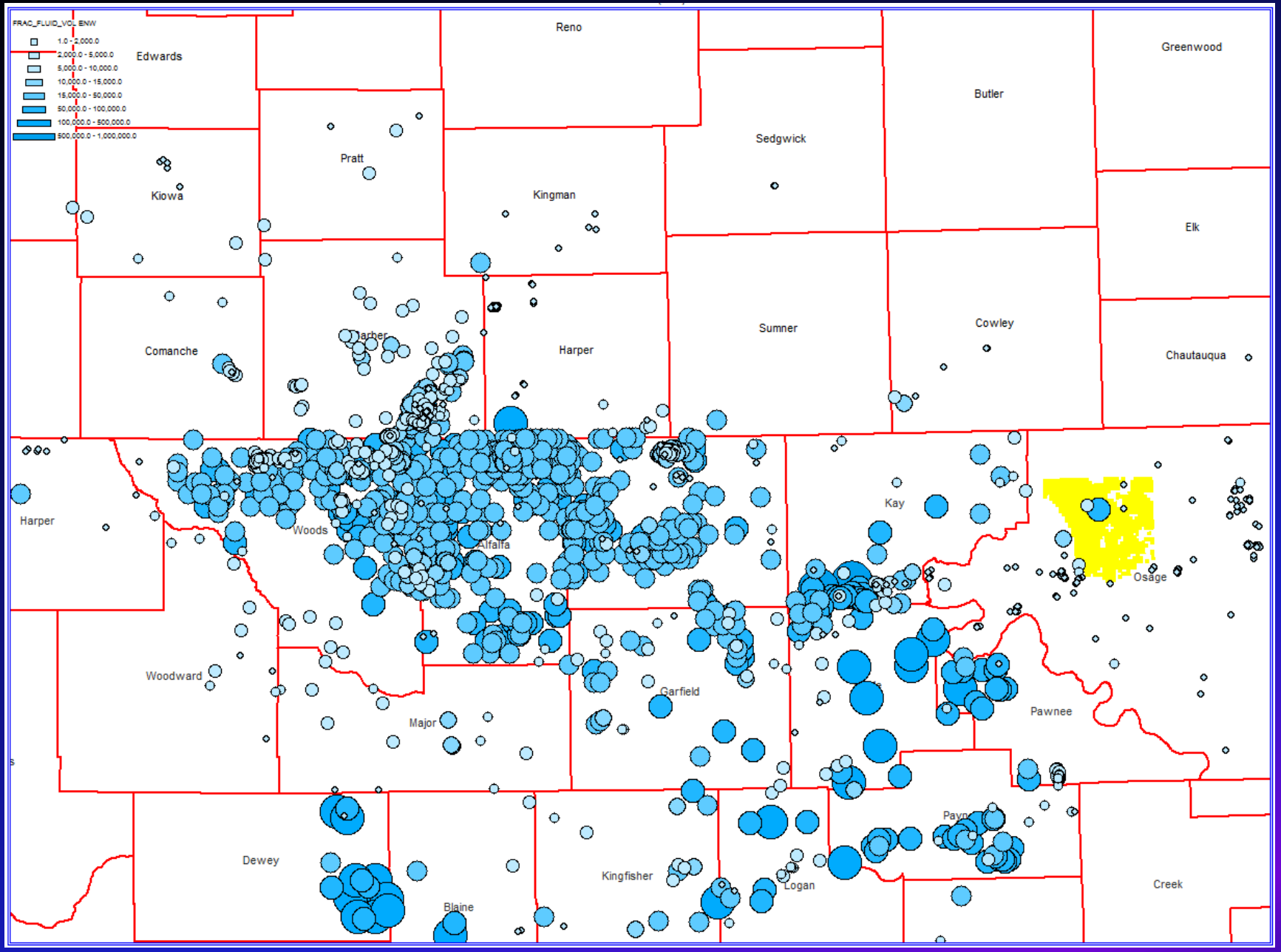
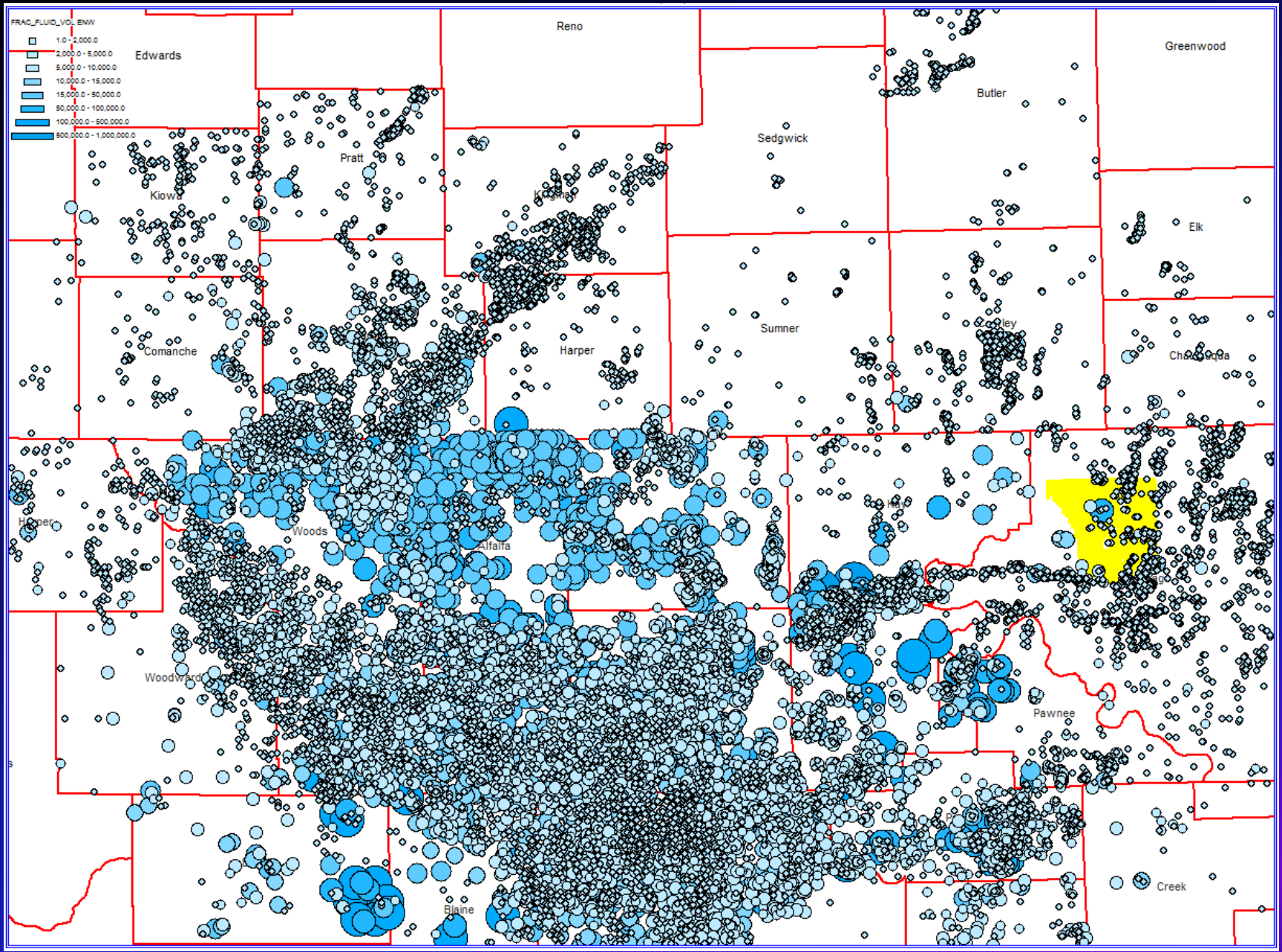
2005-2009



2009 - Present

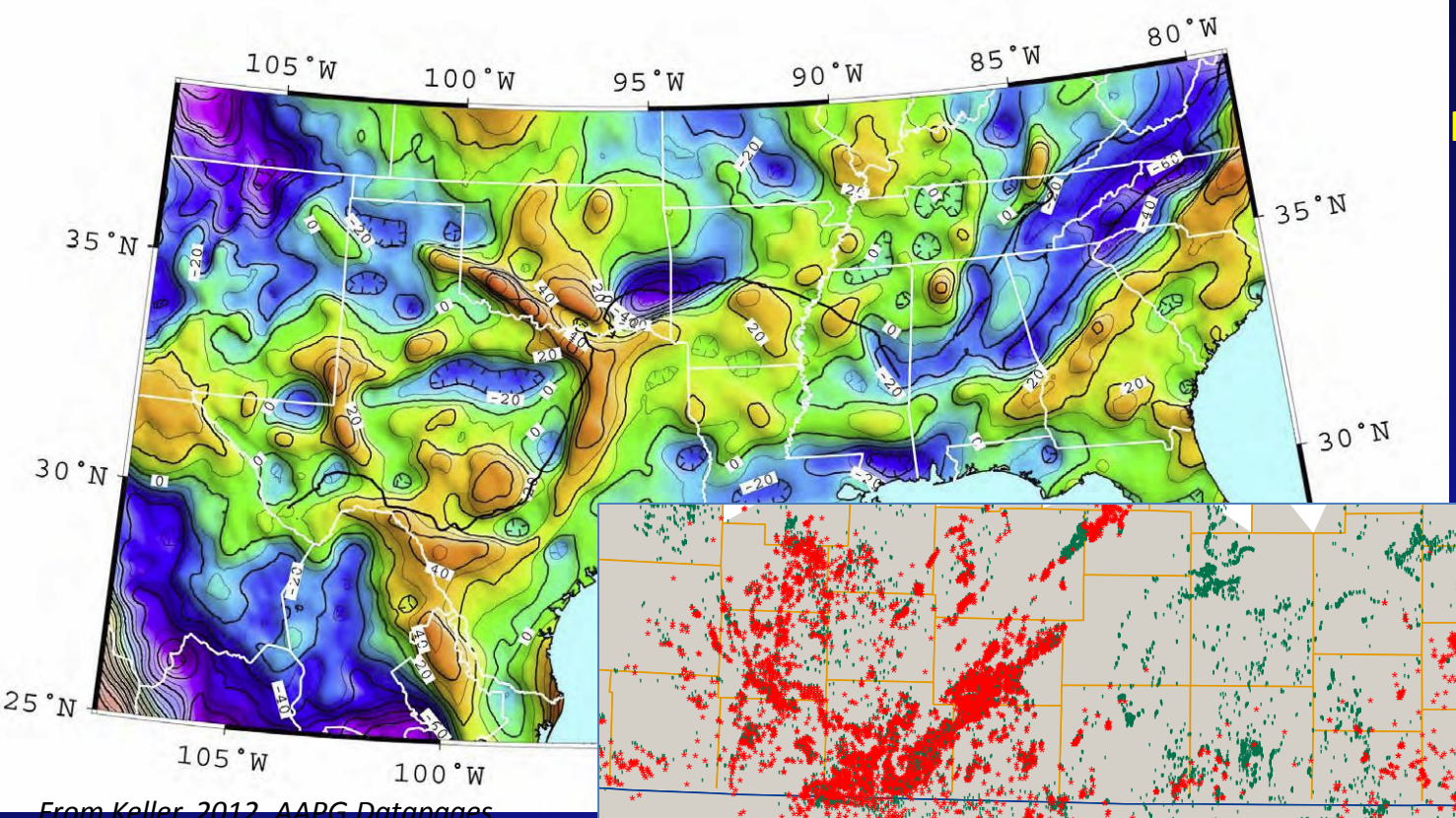


All Completions

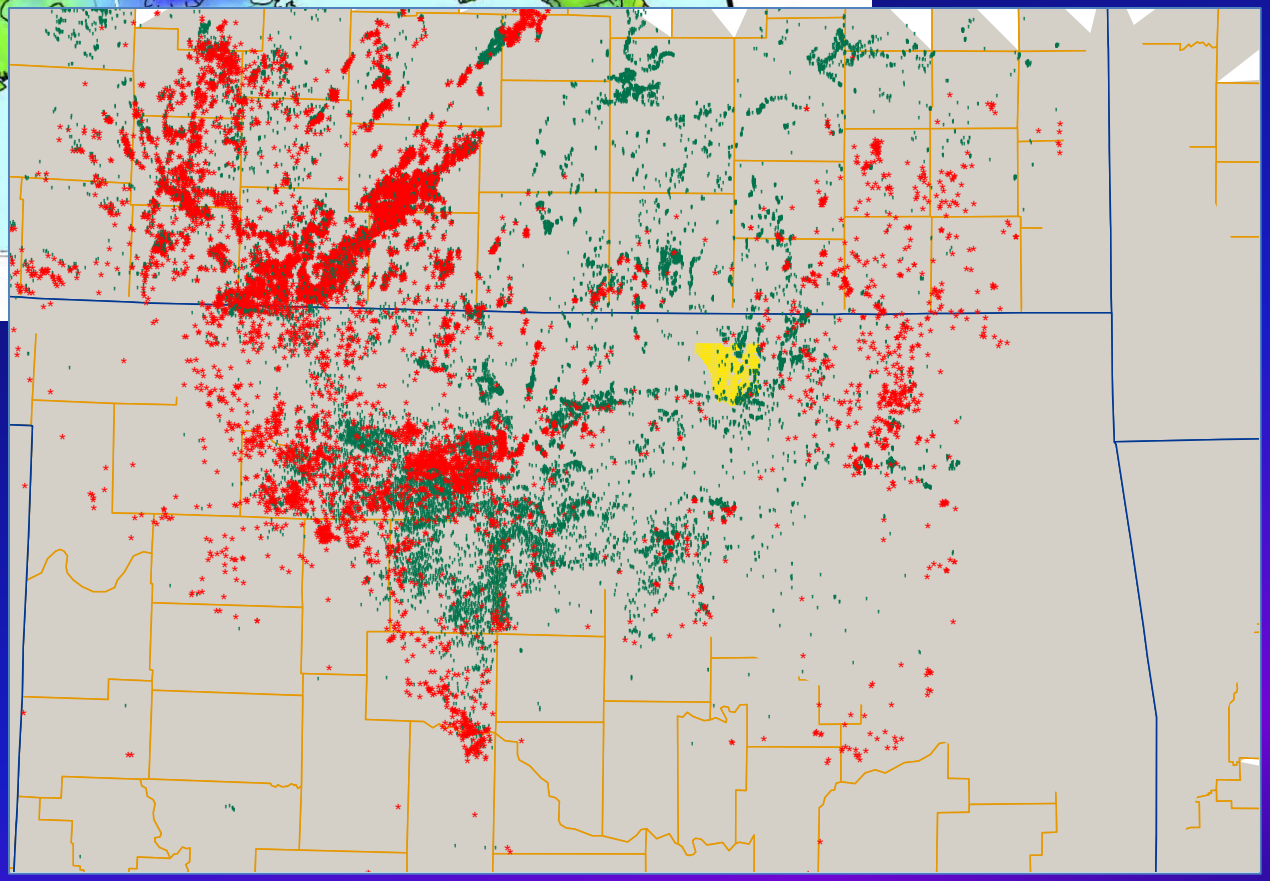
Geological History of Mississippian Reservoirs of OK and KS

- Fine-grained carbonate sands deposited on ramp
- Early diagenetic chert
  - Preferential replacement based on depositional facies (even low-energy deposition is differentiated by grain size across a spectrum)
- Proto-Ouachita Transpressional Tectonics
- Mississippian – Pennsylvanian Unconformity
  - Meteoric impact greatest on pre-existing tectonic-weakened lineaments
- Deposition of Penn Shales
- Continued wrenching of NE Oklahoma – Cracking of the brittle section
- Hydrothermal fluids of unknown origin move laterally through section
  - Tripolization by dissolution of lime
  - Hydrocarbon Filling of traps – World's largest stratigraphic trap?
- Ozark Uplift
- Reversal of dip from west to the east
  - Leak-off of hydrocarbon in high porosity traps
- Hydrocarbon Refill of traps
- Breaching of the reservoir
- Extensional faulting and fracturing due to removal of overburden
- Water moves through the system sweeping higher porosity lithologies

Basement Map
Regional Gravity



From Keller, 2012, AAPG Datapages



Mississippian Vertical
Producing Wells

Mechanical Infrastructure and Knowledge Base

- Operational capability
- Water for stimulation
- Disposal capacity for produced fluids
- Power to run lift

Reservoir Geology

Multiple Reservoir Systems
Conventional – Semi-Conventional - Unconventional

Unconventional
Un-Altered

Semi-Conventional
Altered

Conventional
Highly Altered

2-6% Porosity
Massive Stimulation
Low Natural Deliverability

15-20% Porosity
Stimulation Required
Medium Deliverability

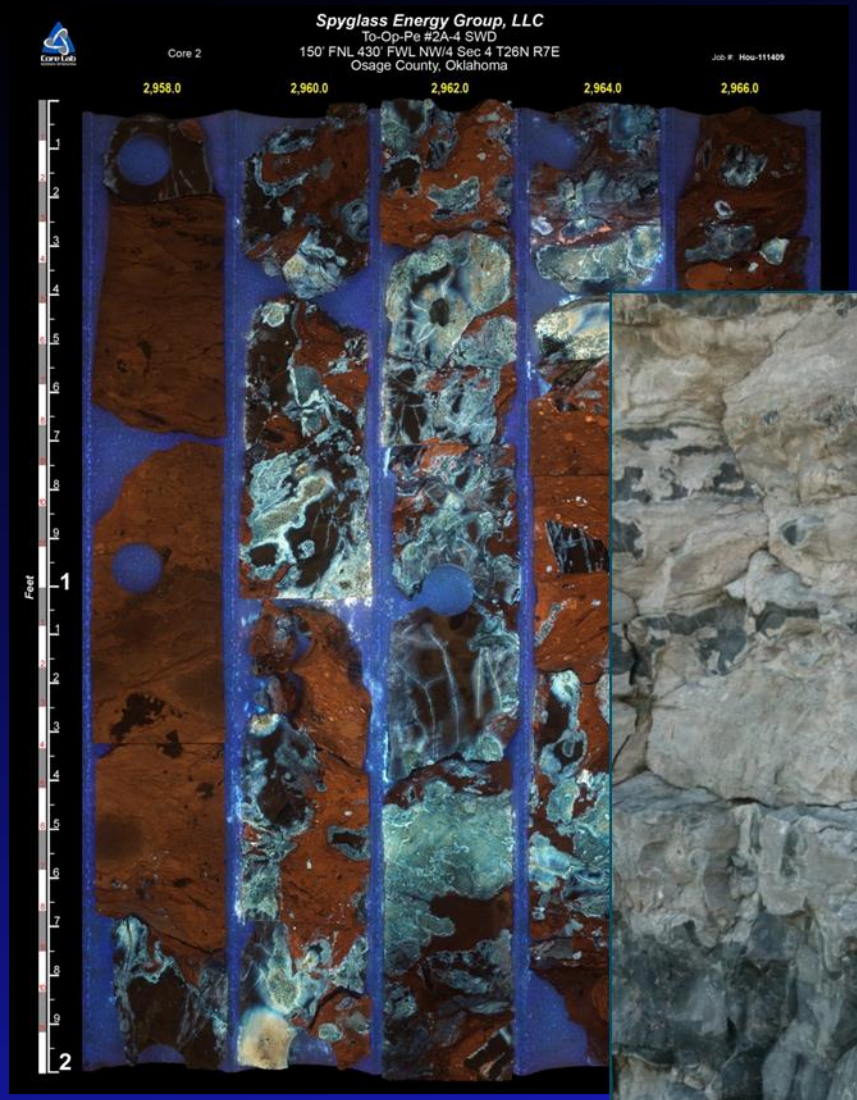
35-48% Porosity
No Stimulation
High Natural Deliverability

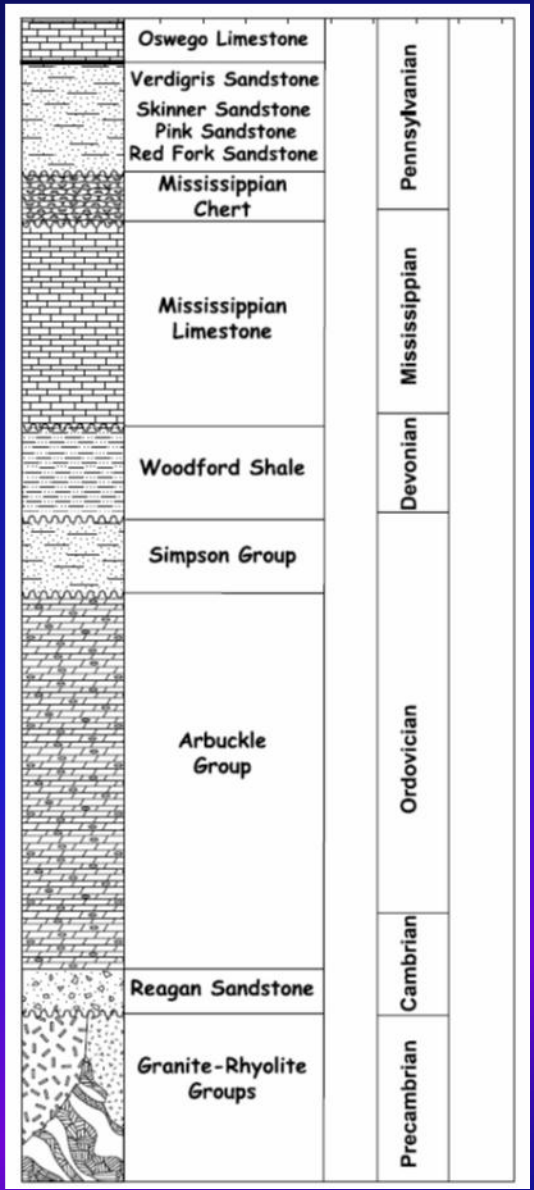
Sweep Efficiency of Hydrological System Increases with Porosity

Reservoir Geology

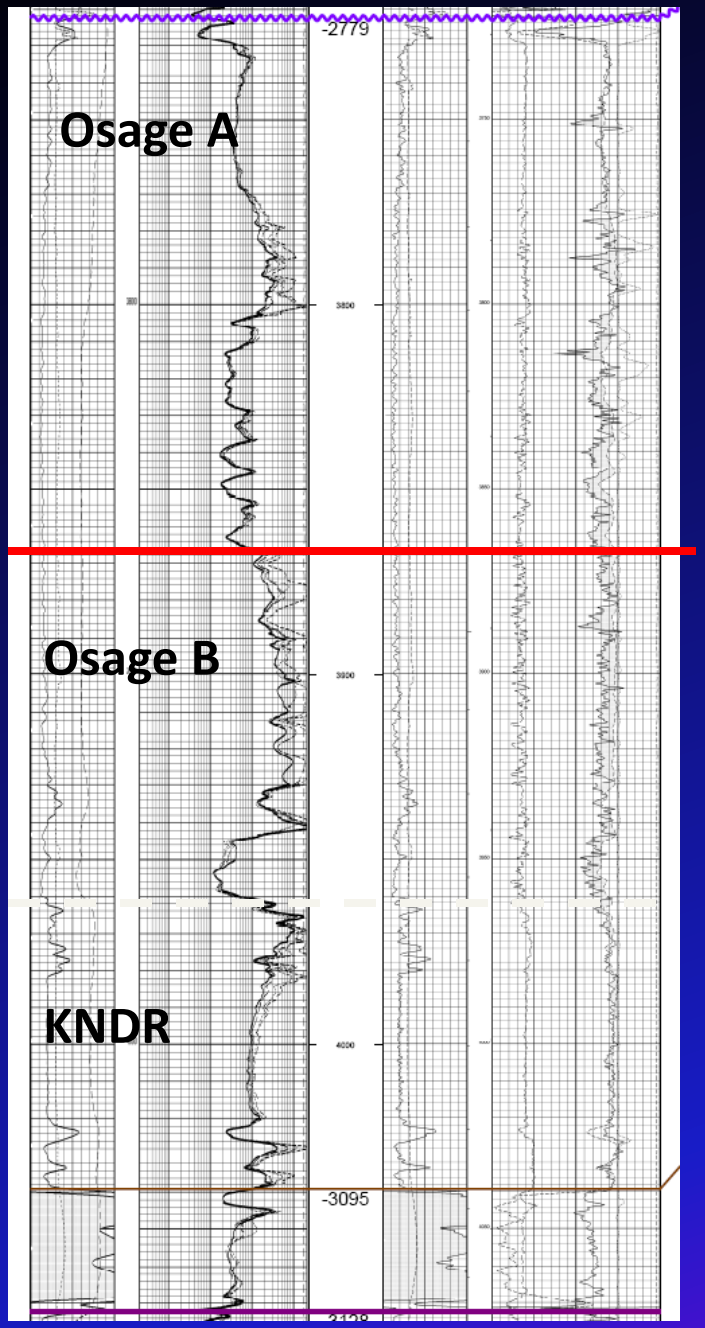
- Porosity System
  - Unaltered Osage A and B
    - Interbedded Chert and Lime
    - Dense “Matrix” Porosity 1-4%
    - Permeability Values 0.1 to 0.5 md
    - Bed-Boundary Porosity System
      - “True Matrix Porosity”
    - Micro-Porosity – Methane Storage
  - Altered Osage A and B
    - Porosity values 6 – 18%
    - Permeability .05 to 8 md
  - Highly Altered Osage A and B
    - Porosity Values 35 – 42%
    - Permeability Values 0.2 to 20 md
- Fracture System
  - Mega-Fractures – Seismically Defined, Compaction and Tectonic Origins
  - Bed- Bound Fractures – Extensive and dominant in beds with high SiO_2
  - Micro-Fracture

Reservoir Geology





Reservoir Geology



Osage A – Unaltered

Silicified Limestone

High Diagenetic Susceptibility

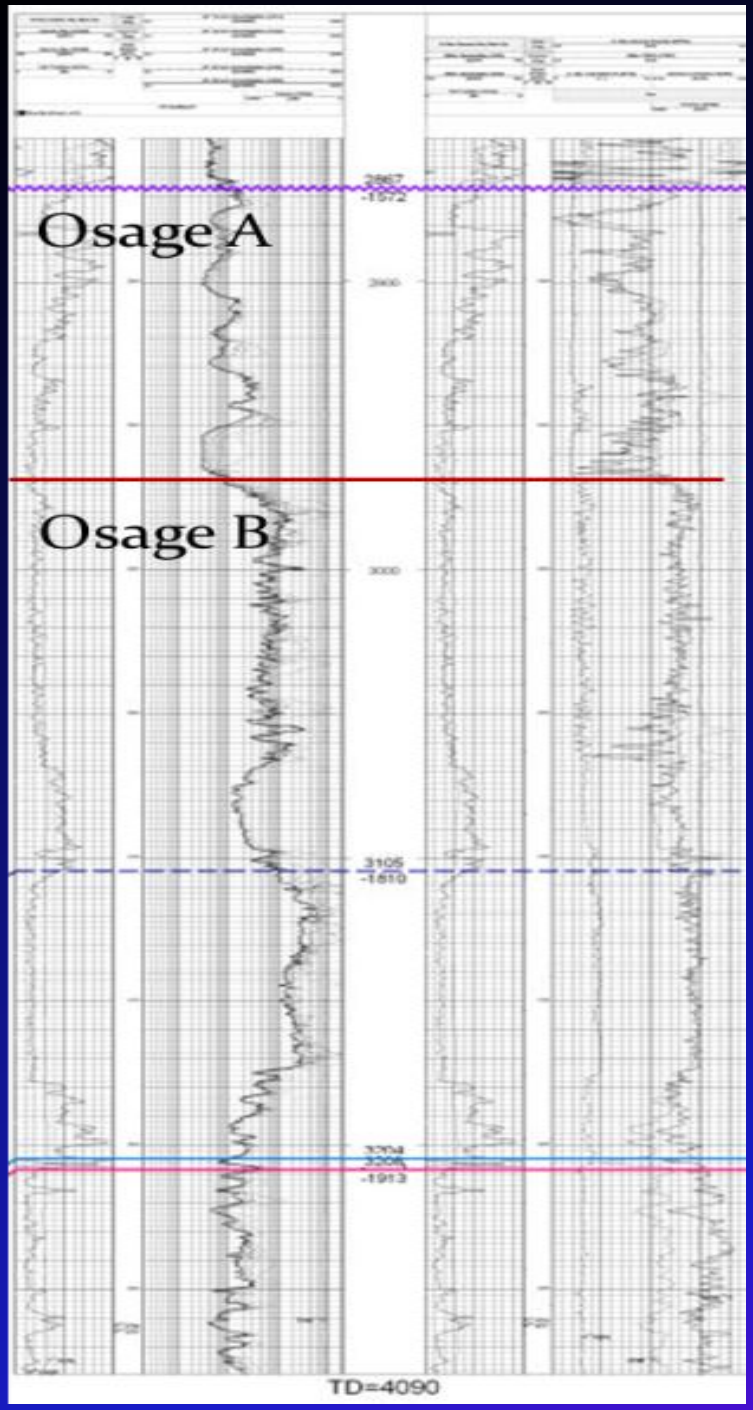
Osage B – Unaltered

Interbedded Chert and Lime

Low Diagenetic Susceptibility

Kinderhook Limestone

Mississippian Reservoirs of Northeast Oklahoma



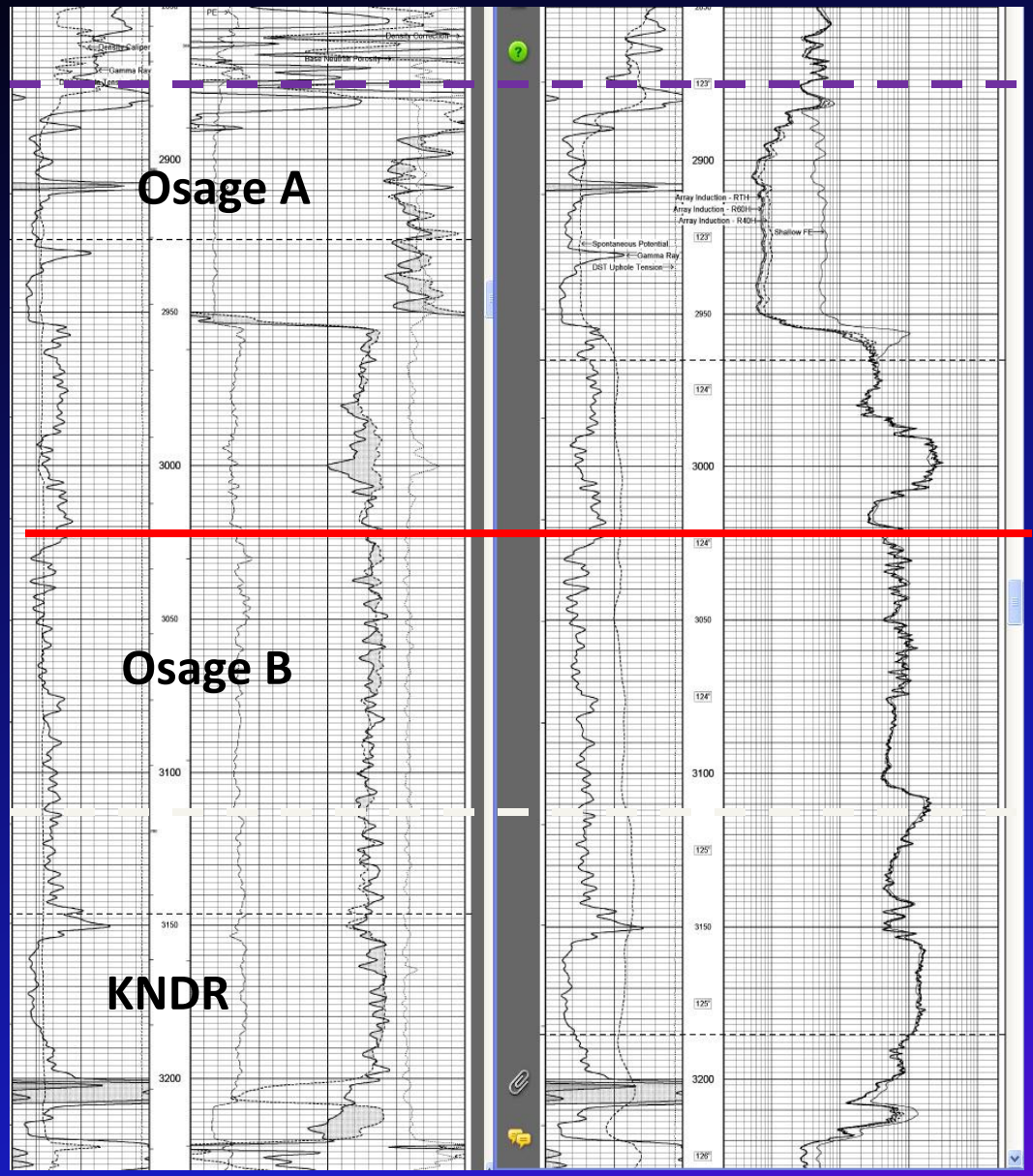
Osage A – Altered

High Degree Diagenetic Susceptibility

Osage B – Unaltered

Kinderhook Limestone

Reservoir Geology



Osage A – Highly Altered

Osage B – Unaltered

Kinderhook Limestone

NW Strohm 2-29 SWD

TWP: 26 N - Range: 7 E - Sec. 29
Datum=1160

44310 ft

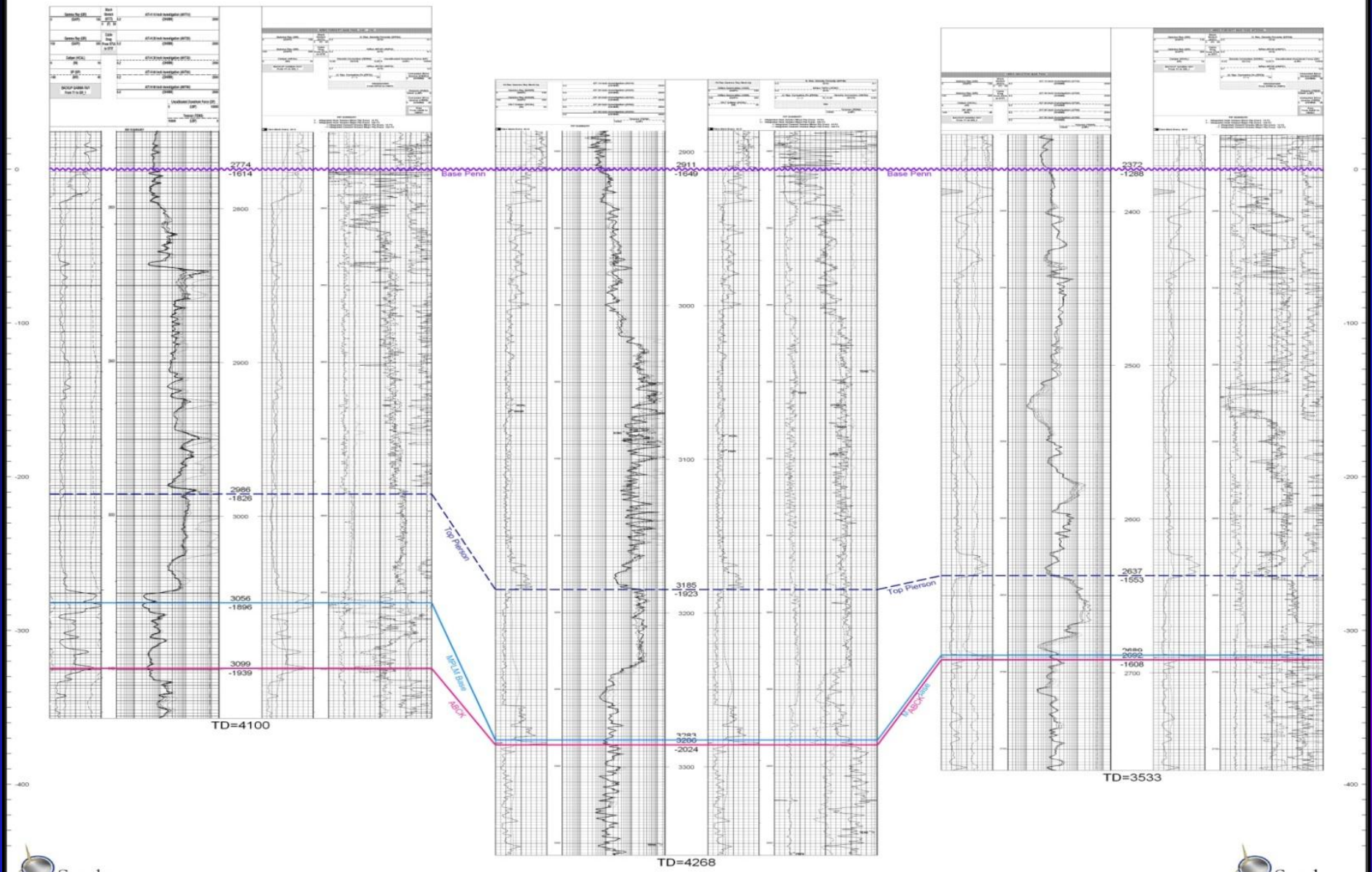
Shaw 5A-8 SWD

TWP: 27 N - Range: 7 E - Sec. 8
Datum=1262

44126 ft

Hickory Creek 2A-22 SWD

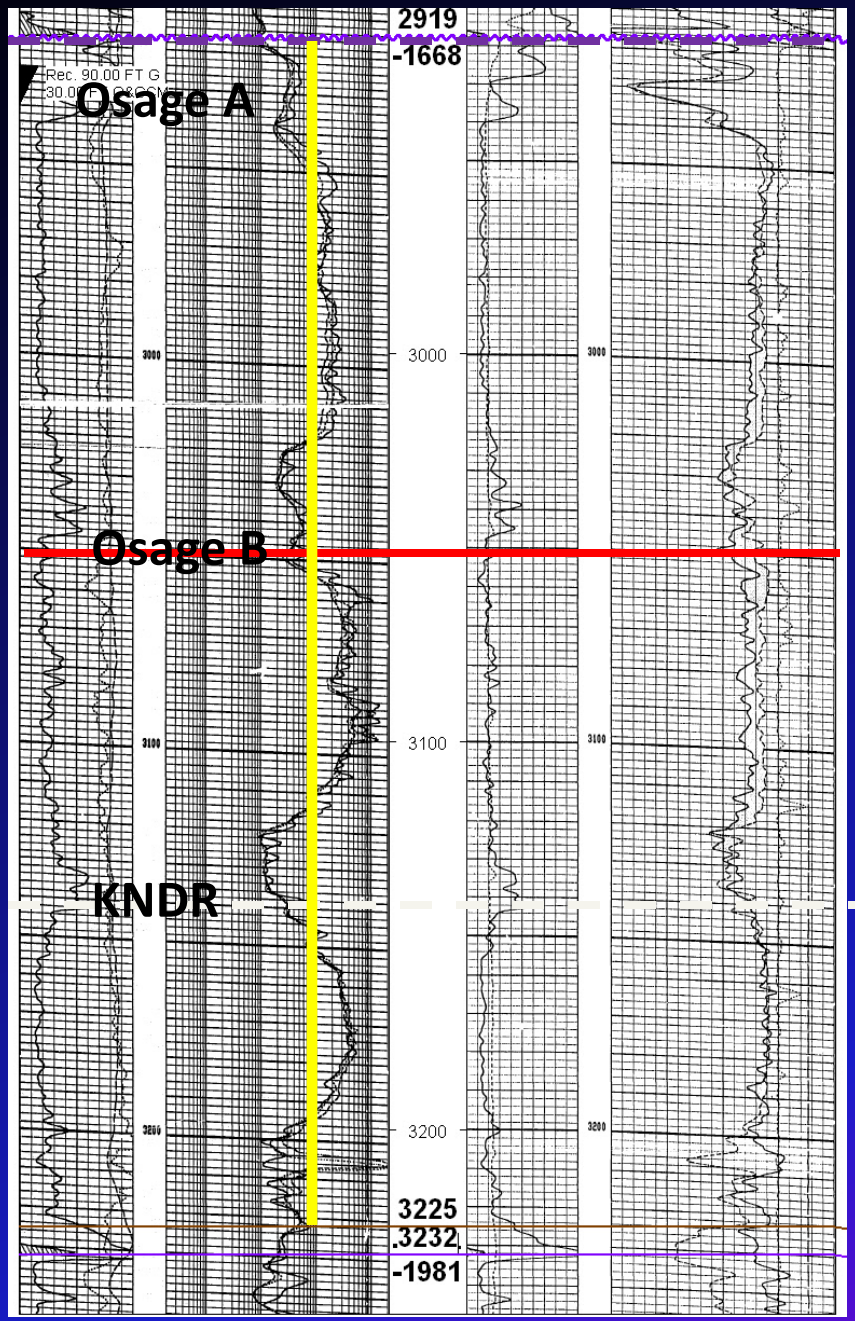
TWP: 27 N - Range: 8 E - Sec. 22
Datum=1084



Spyglass Energy Group, LLC "Focused on the Future"

Spyglass Energy Group, LLC "Focused on the Future"

Unaltered A and B



Altered A and B

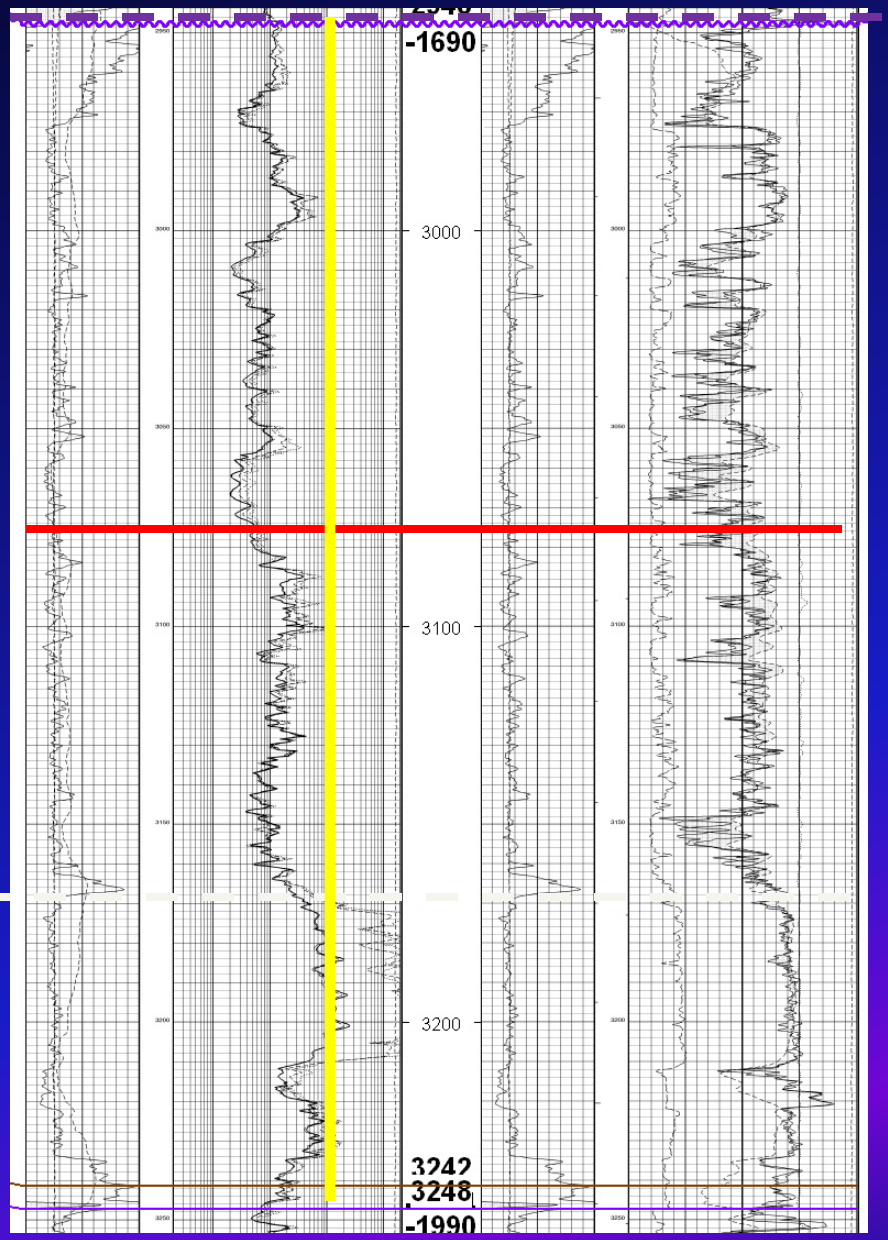
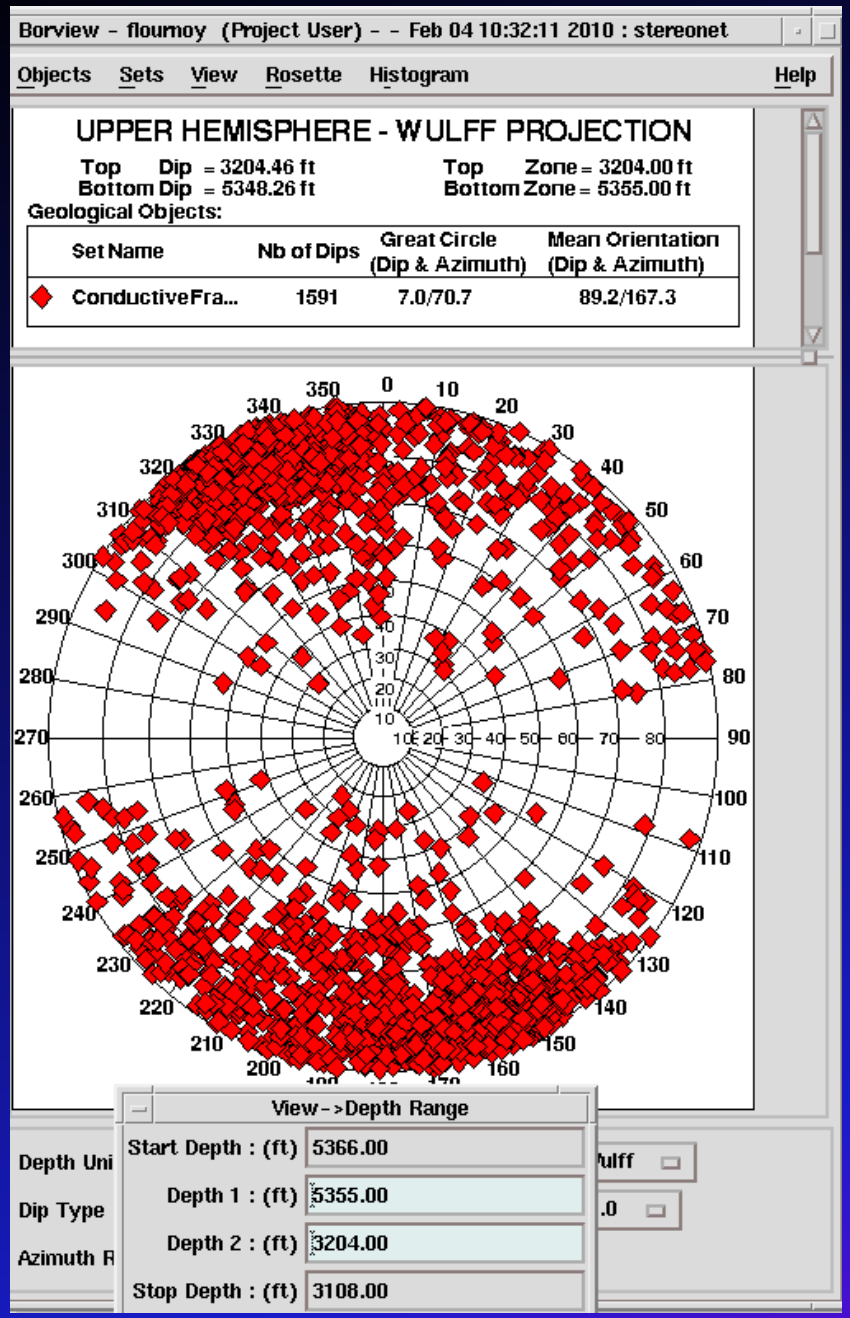
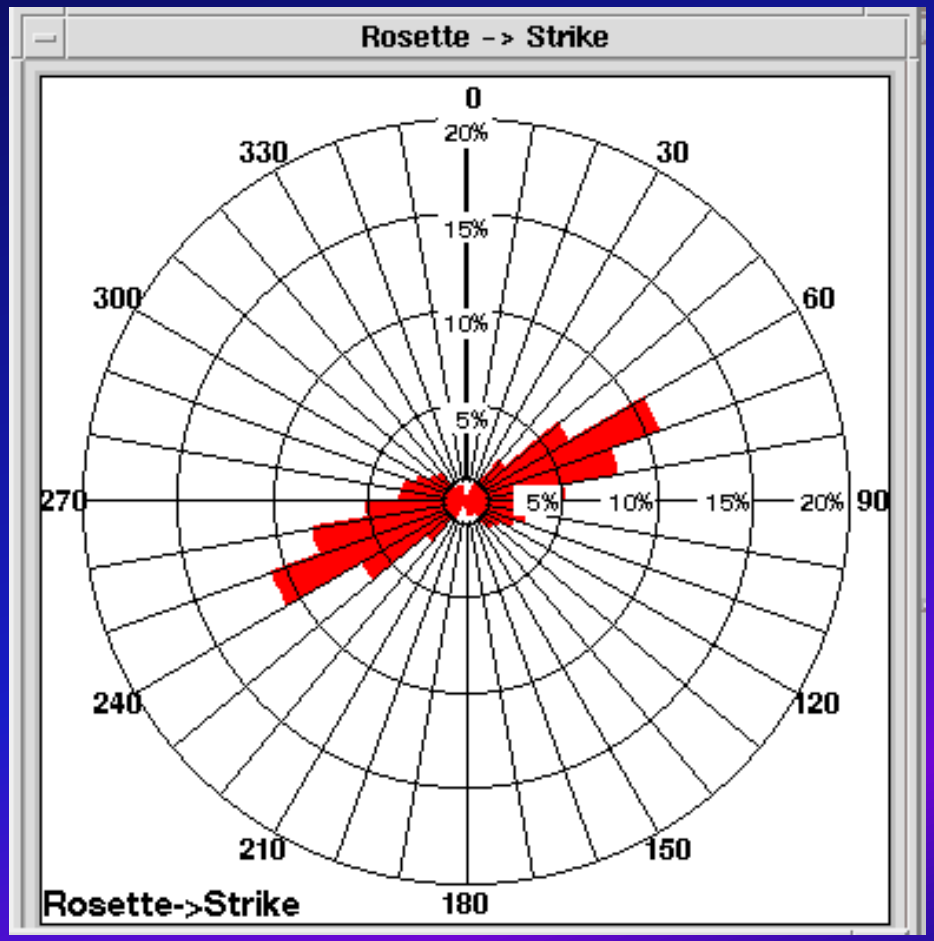


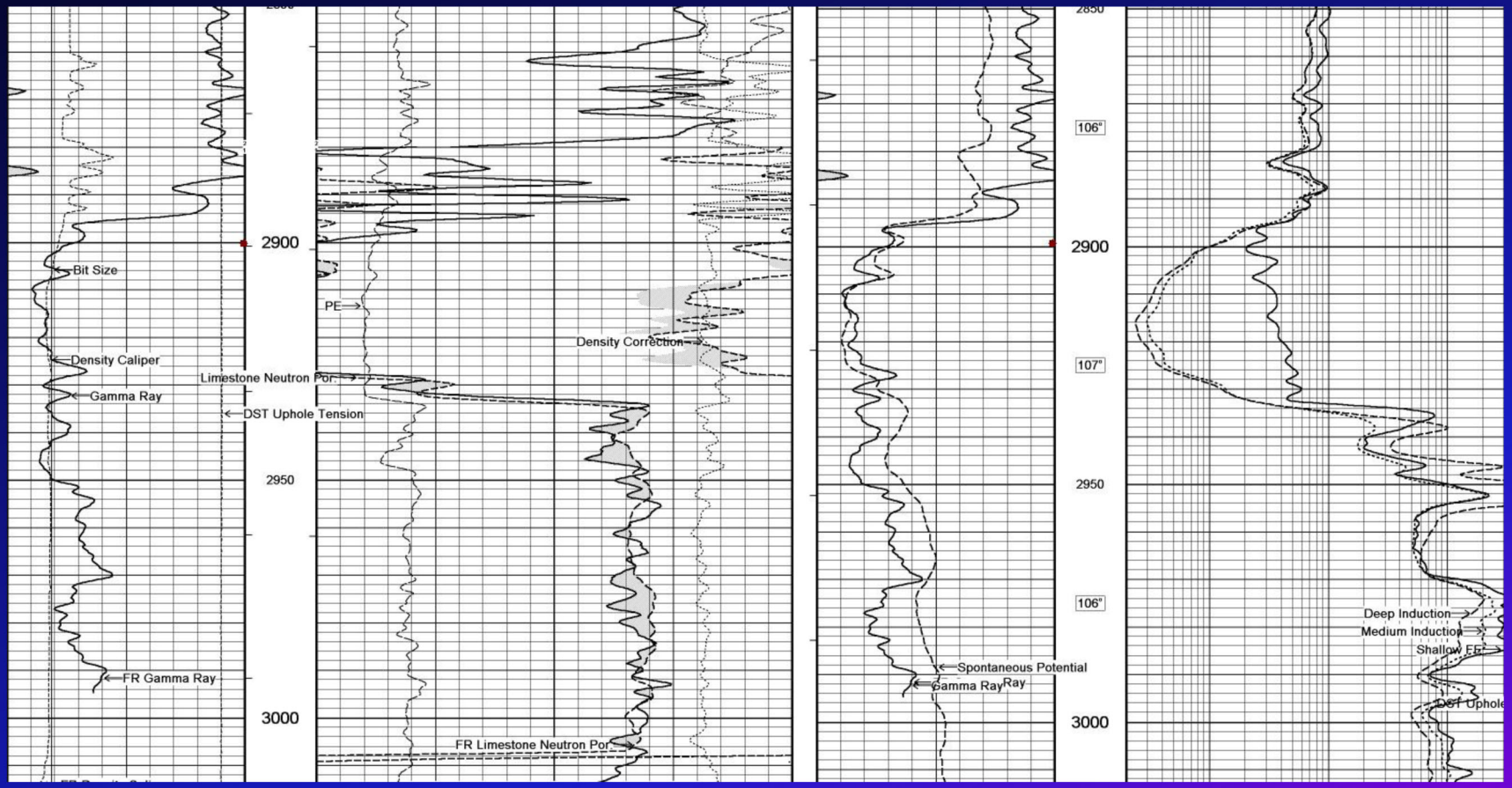
Image Log Fracture Quantification – Shattered Rock



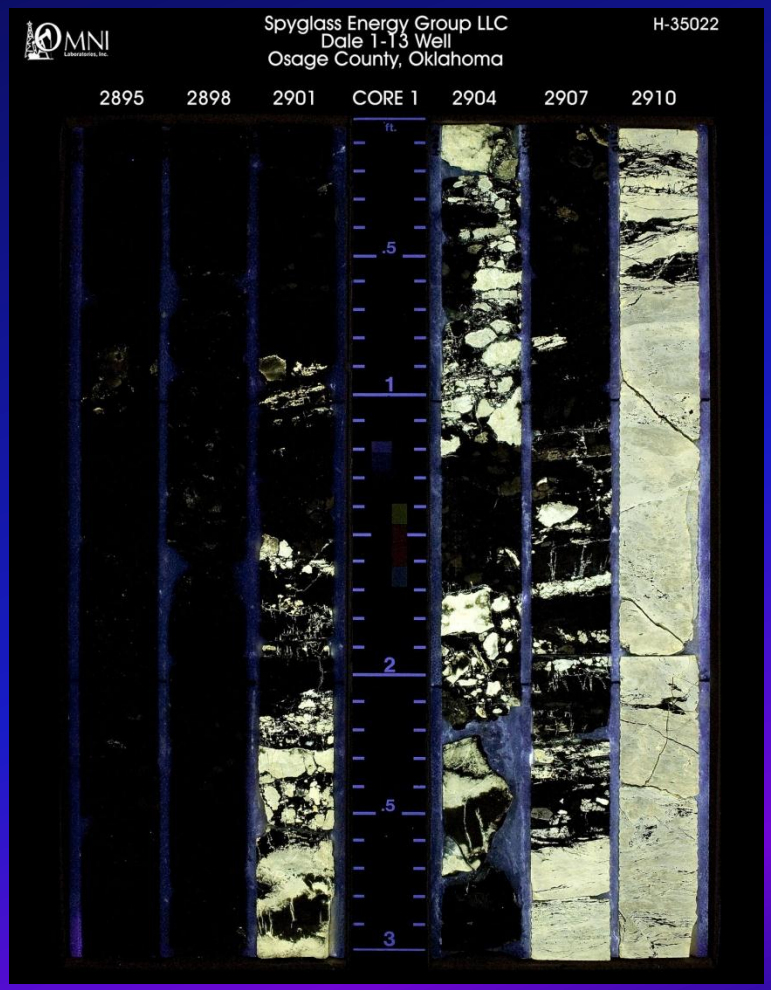
- 2350' of lateral interpreted
- 1591 open natural fractures
- Fracture Density – 10 / ft
- Strike N 70 E



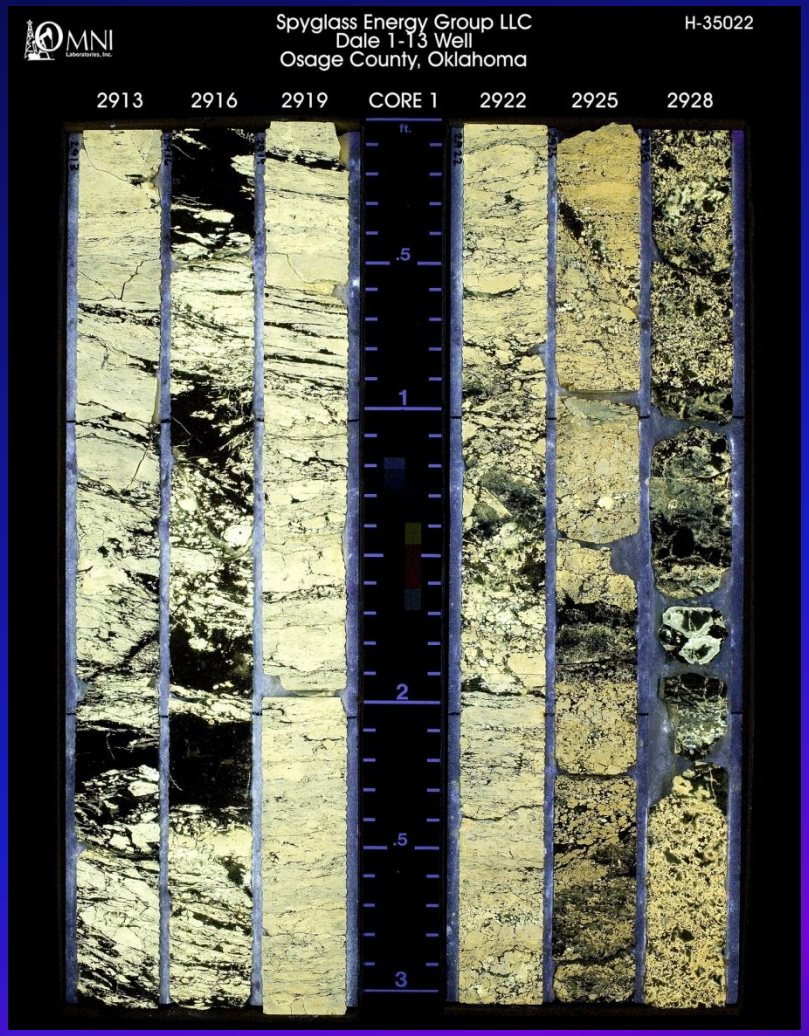
HW 60 “Chat Subcrop Play”



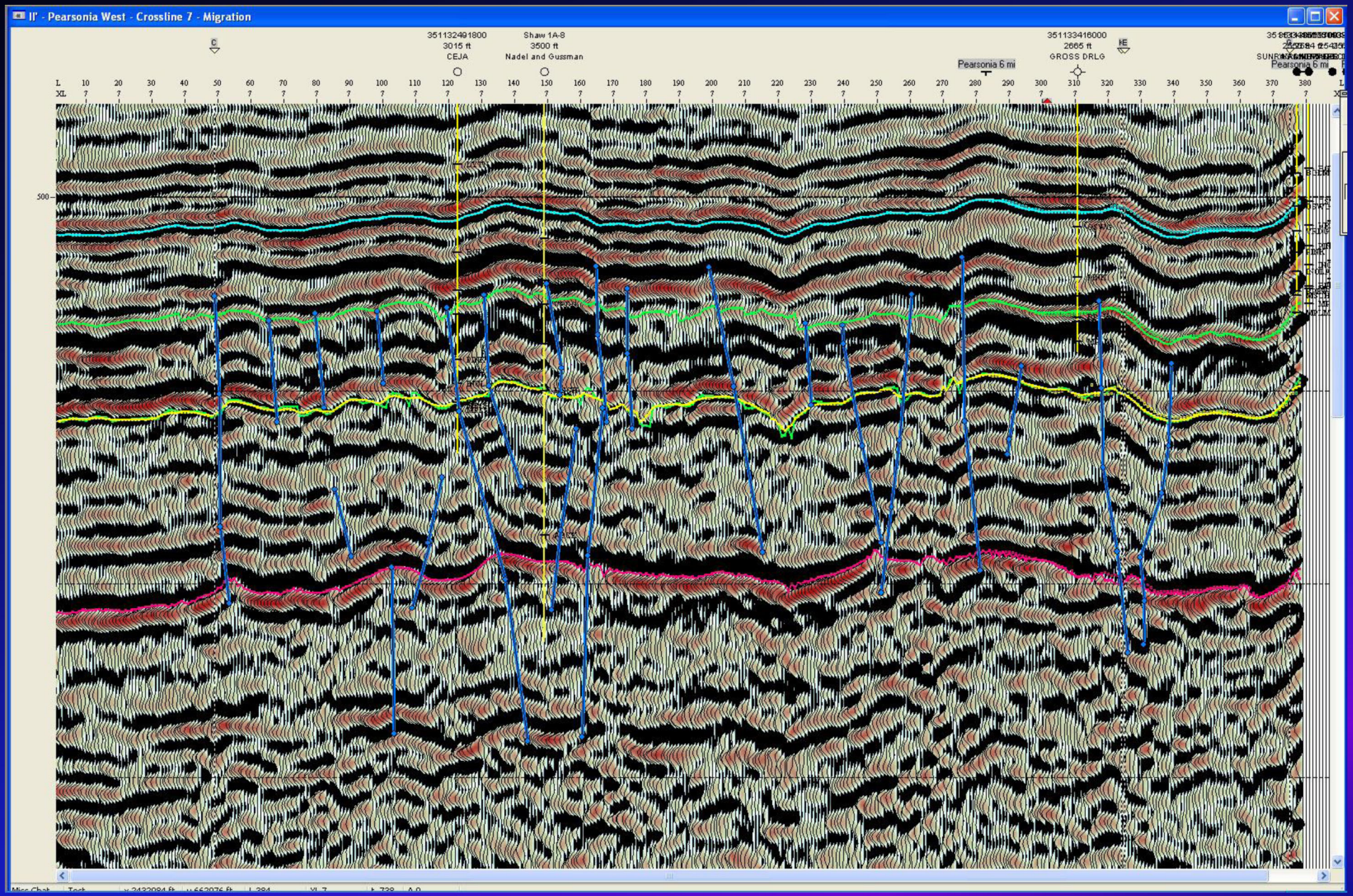
Chat Core Photo (2895 – 2913)



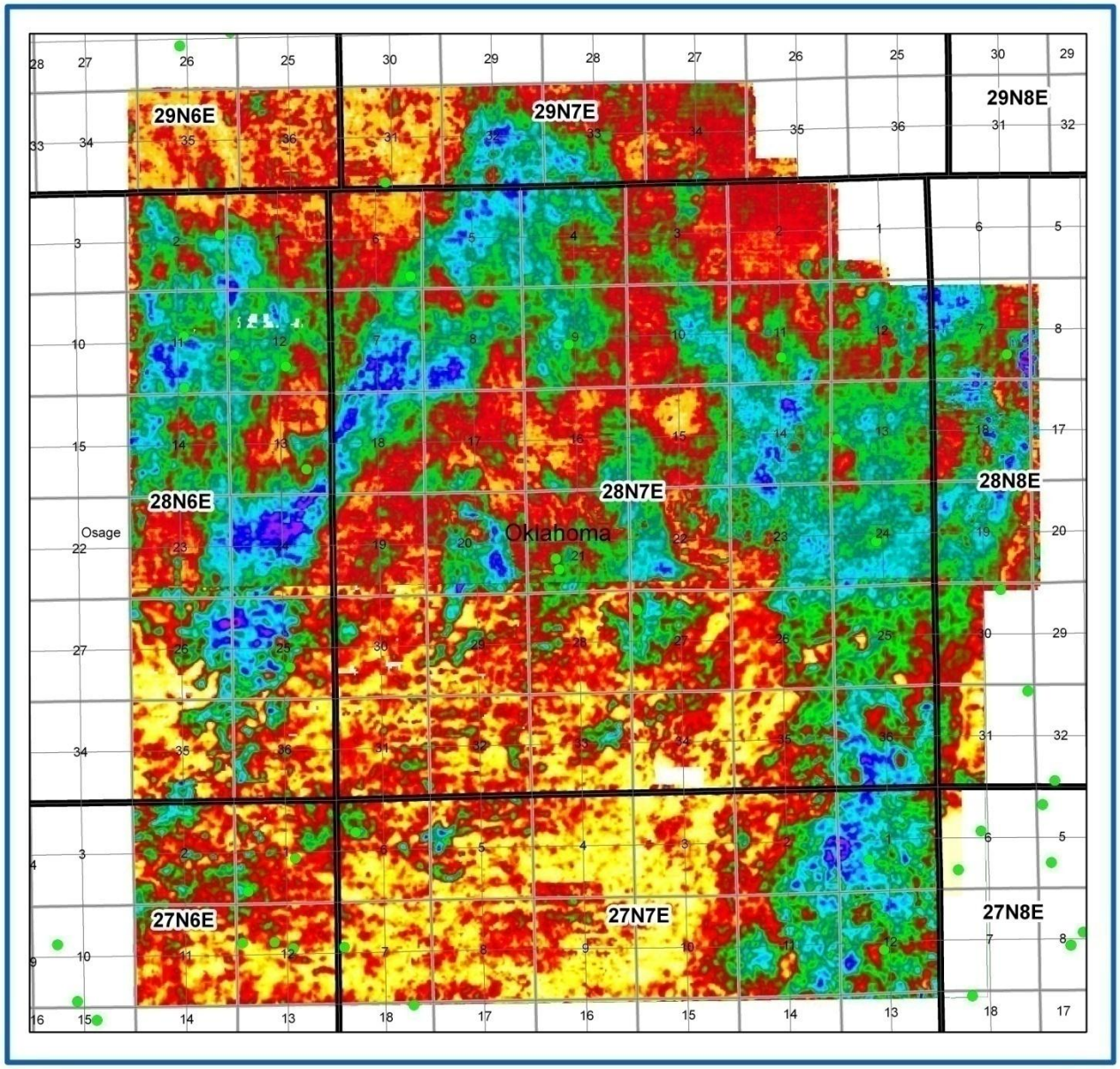
Chat Core Photo (2913 – 2931)



3D seismic shows evidence of extensive wrenched terrain. Diagenetic overprint too great and spatial density of wells too sparse to recognize strike slip fault systems.



MississippSeismic "Chat" Stratigraphy



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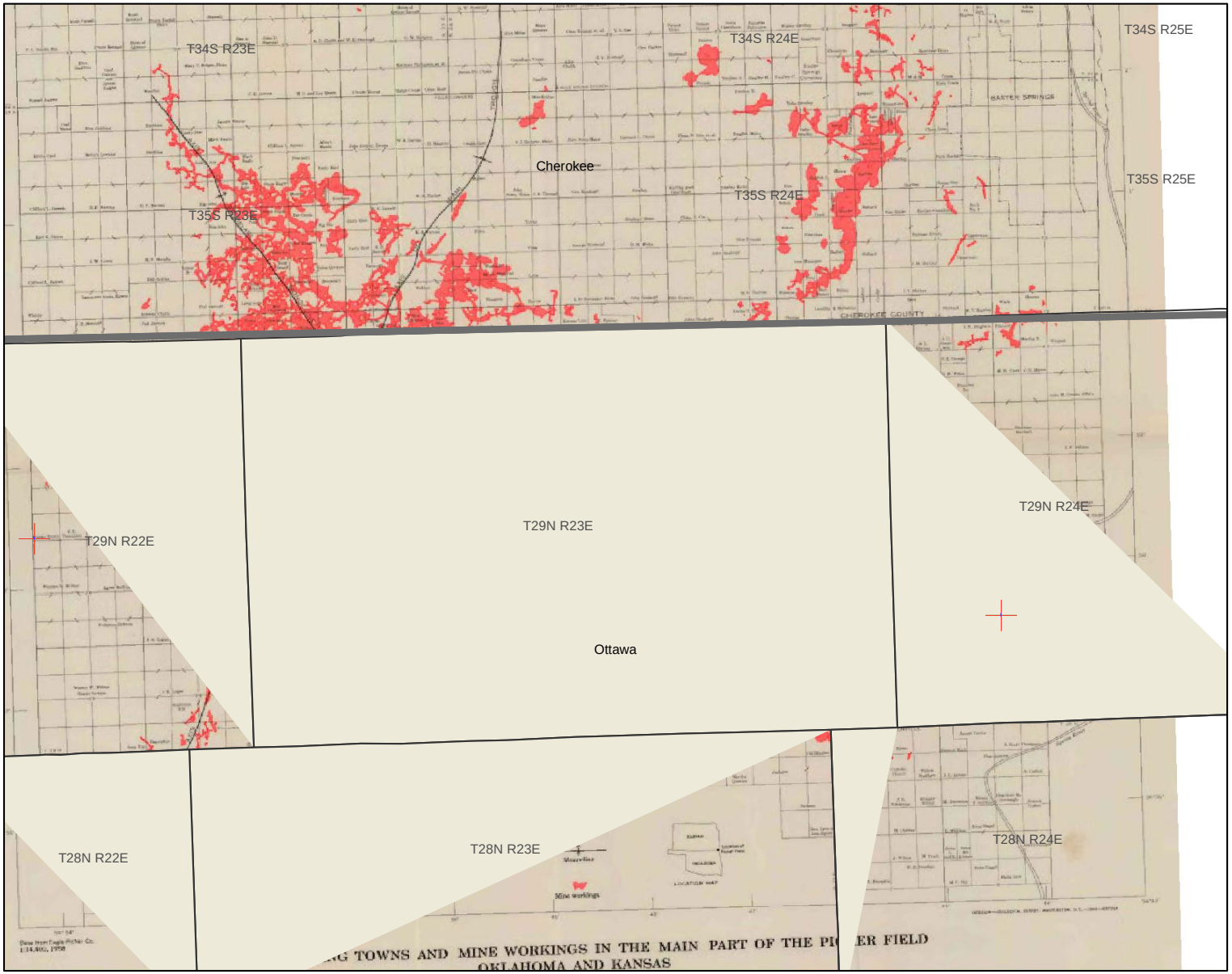
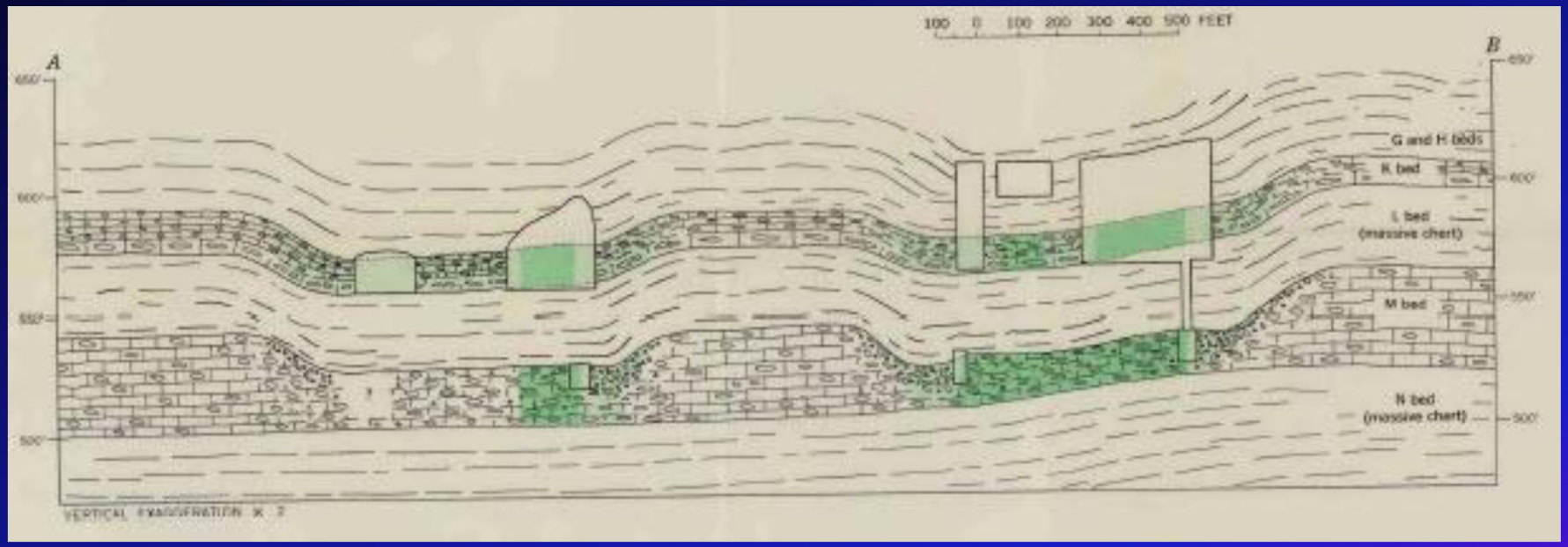


Plate 11 - Mine Workings of the Picher Field

The Tri-State host rock is Mississippian chert breccias and tripolites in a horst-and-graben terrain



3500’

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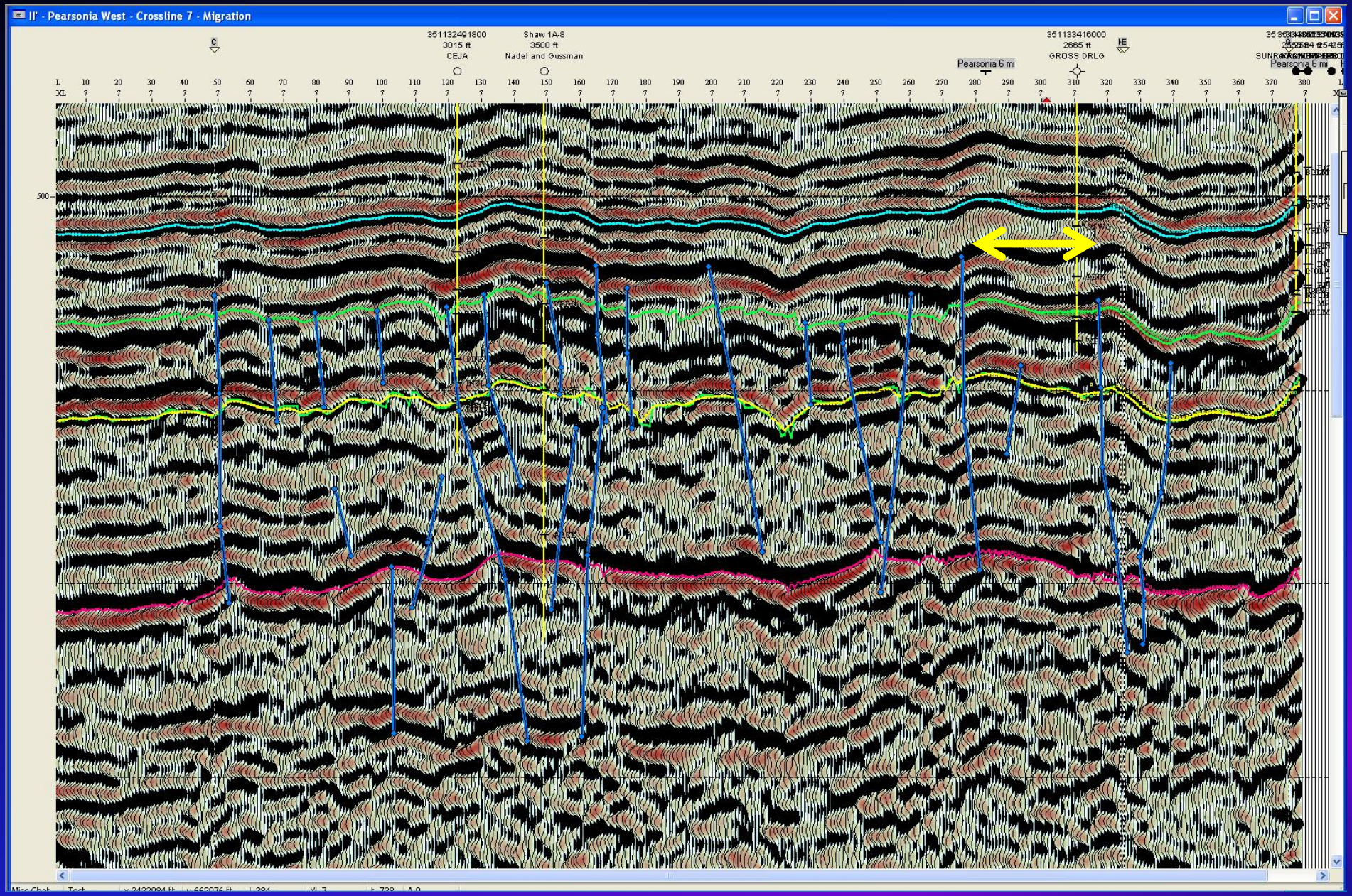
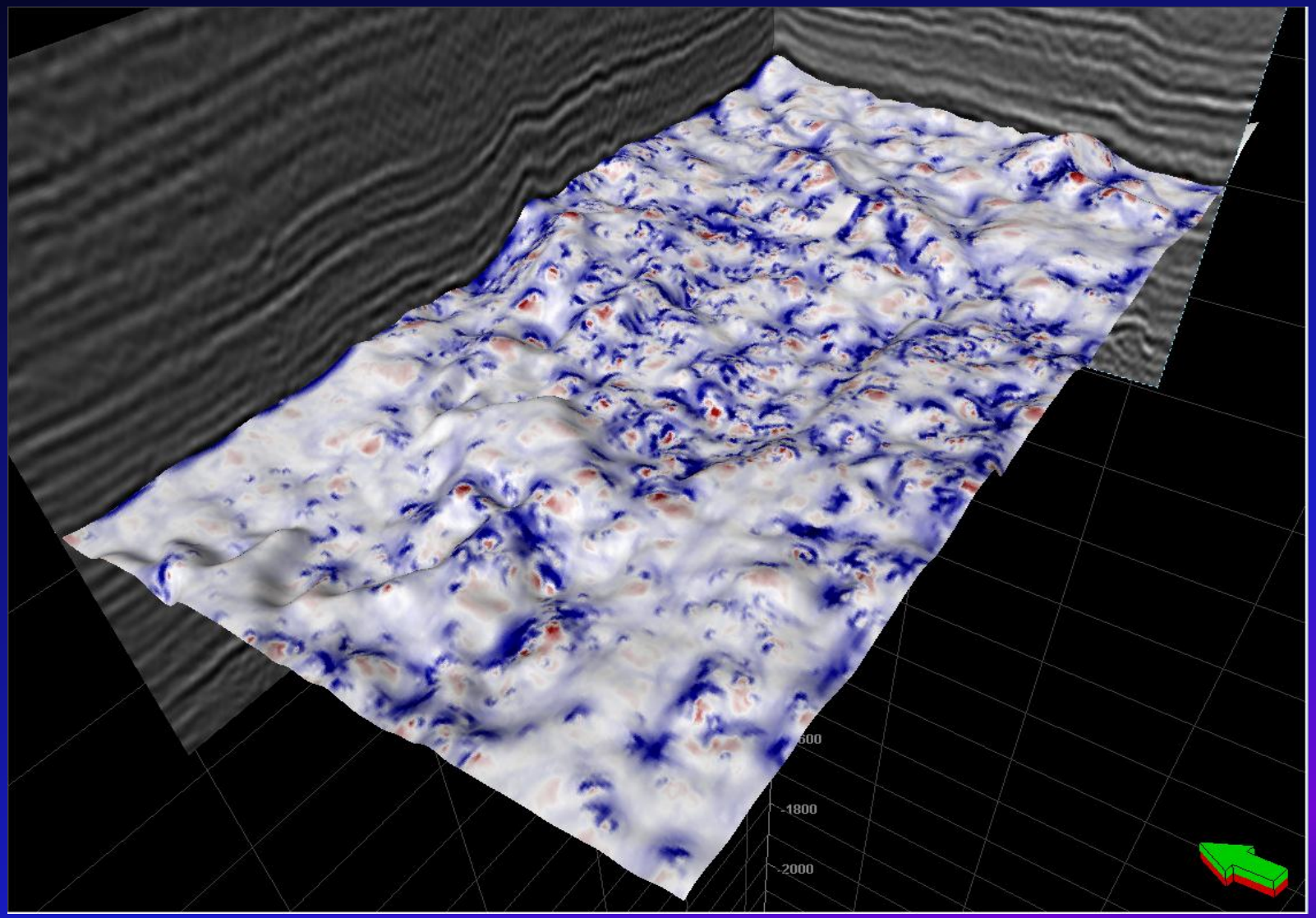
East West seismic section – Length eight miles



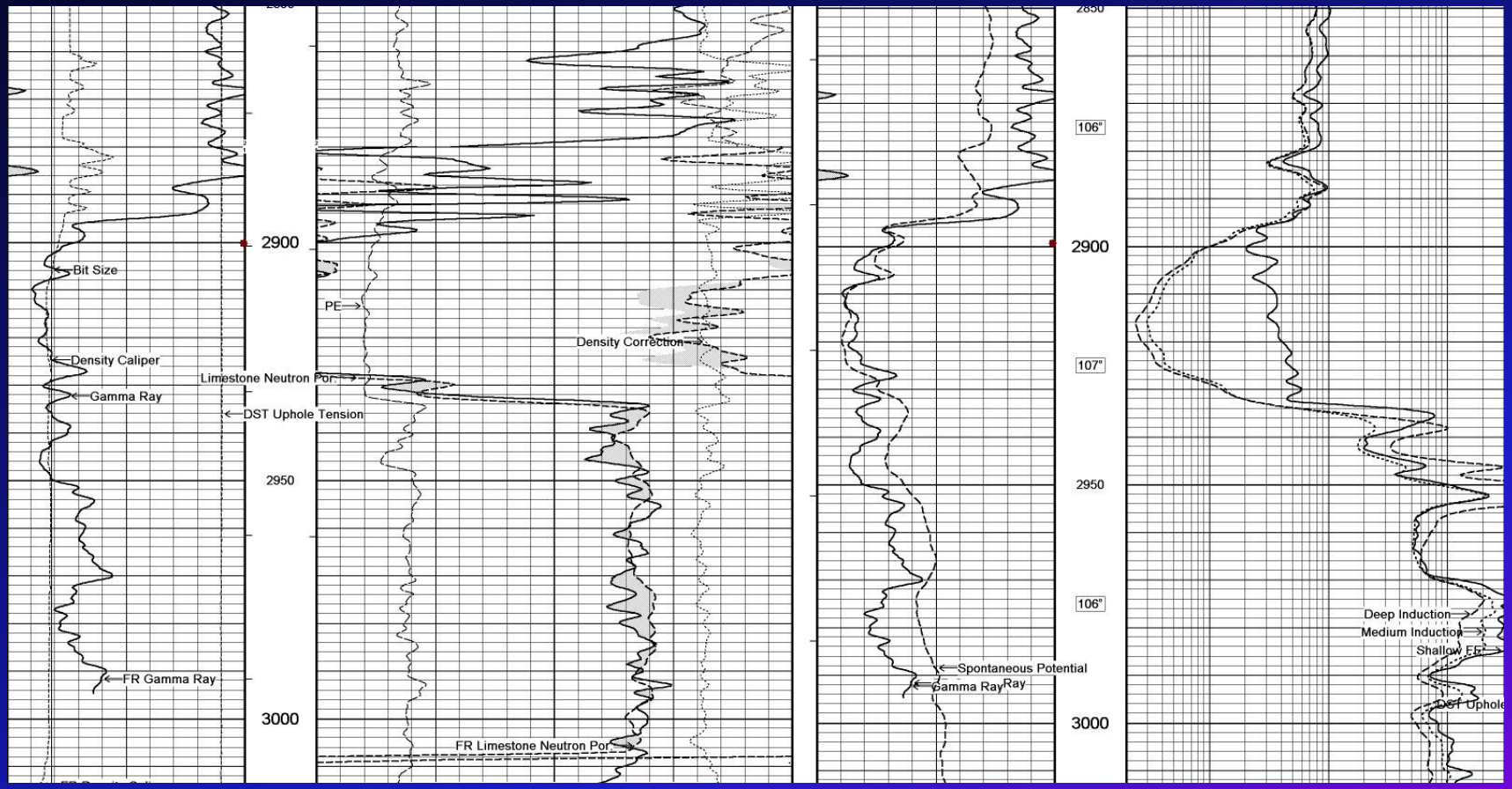
Structure: Seismic



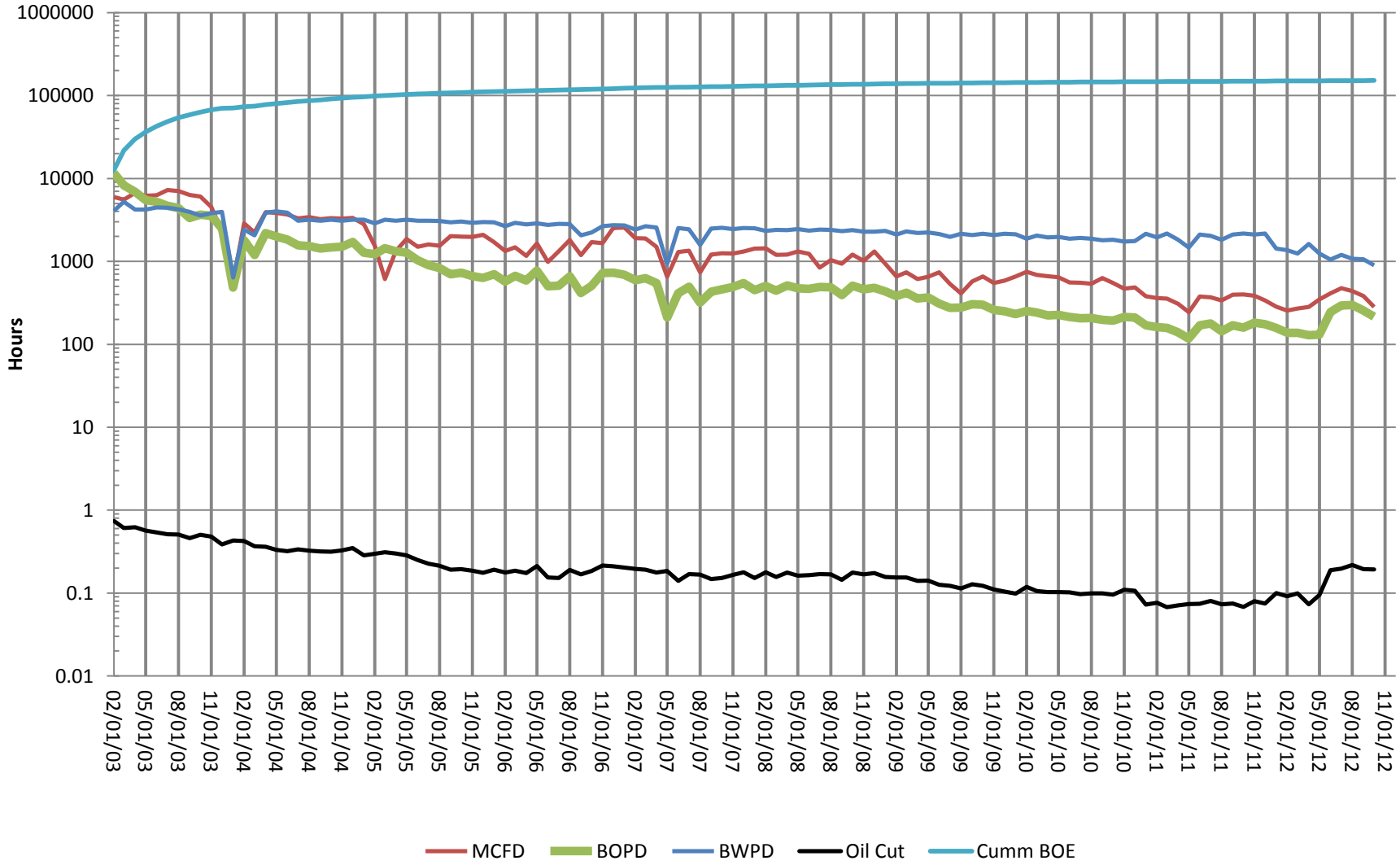
Reservoir Stimulation

- Conventional (35 – 48% Porosity)
  - Open Hole No Stimulation
- Unconventional (4-8% Porosity)
  - Massive Stimulation
  - Possible to UNDERSTIMULATE
- Semiconventional (12-25% Porosity)
  - Possible to OVERSTIMULATE

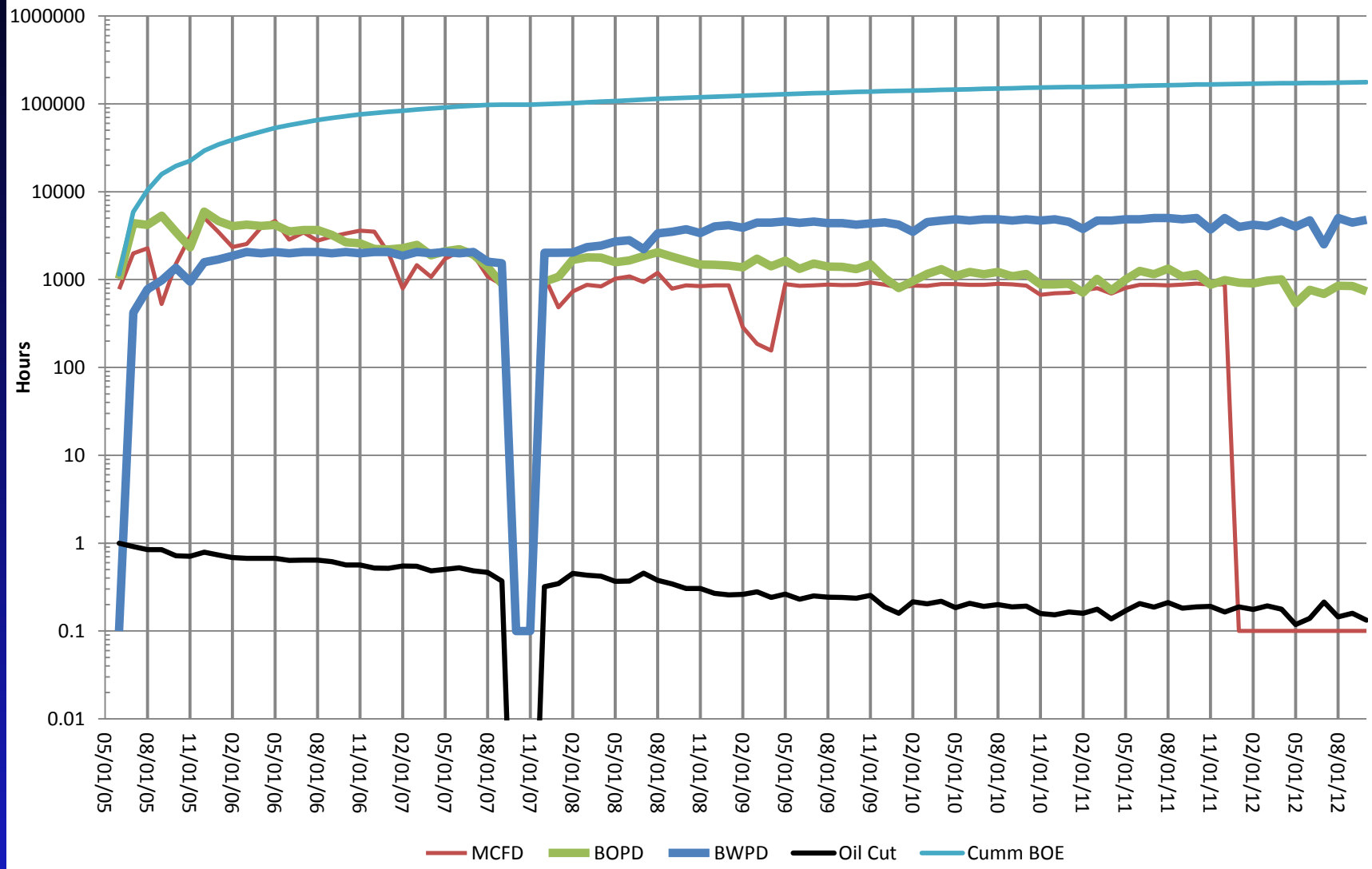
Conventional Stimulation



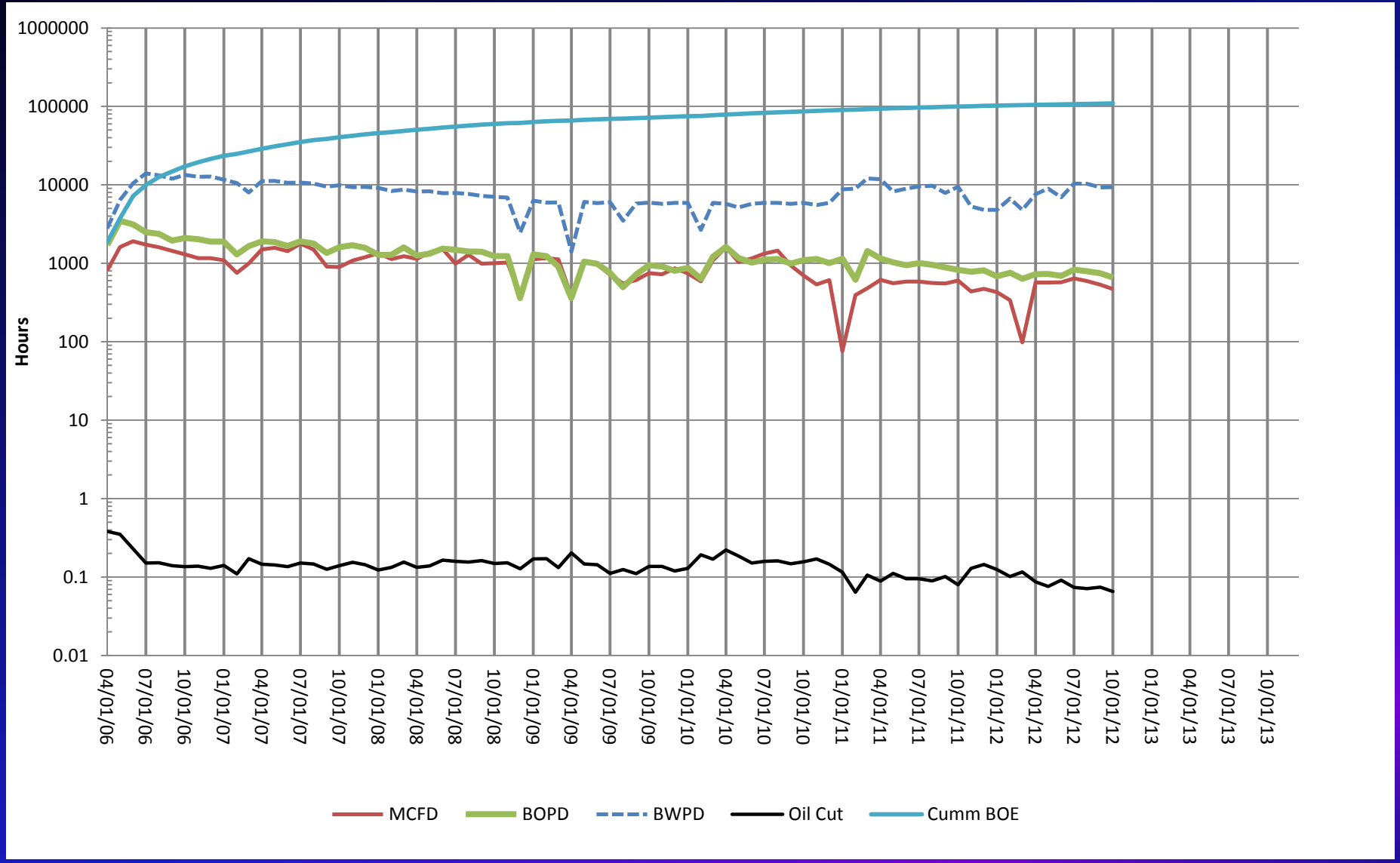
Benjamin 4H
Sec 10 T25N R3E
First Production February 2003
Cumulative Production 152,00 BOE (89% Oil)
EUR 183,000 BOE



Williams 3H
Sec 3 T25N R4E
First Production June 2006
Cumulative Production 176,200 BOE (89% Oil)
EUR 257,000 BOE



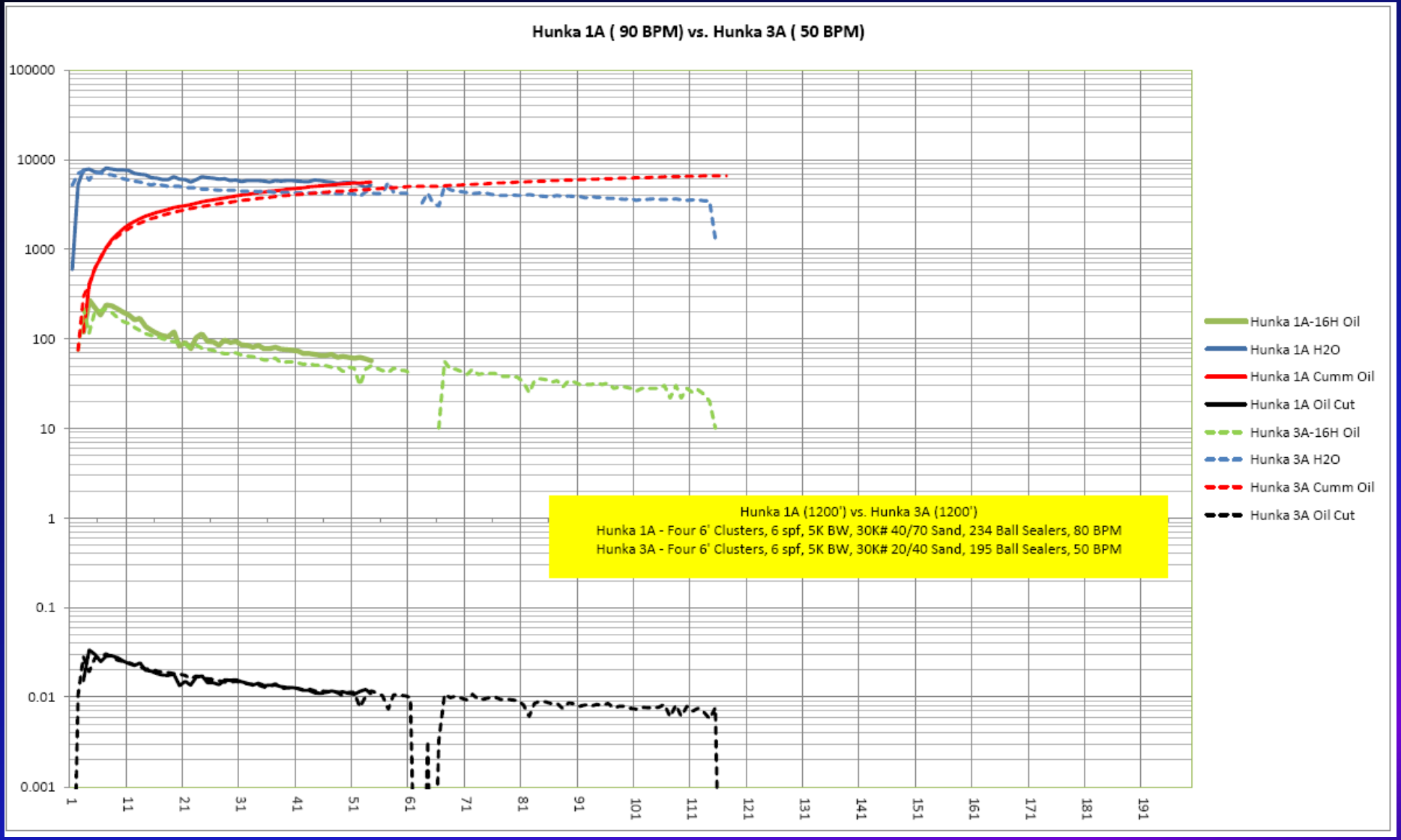
Lenker 6H
Sec 5 T25N R5E
First Production April 2006
Cummulative Oil Production 110,000 BOE (88% Oil)
EUR > 200,000 BOE



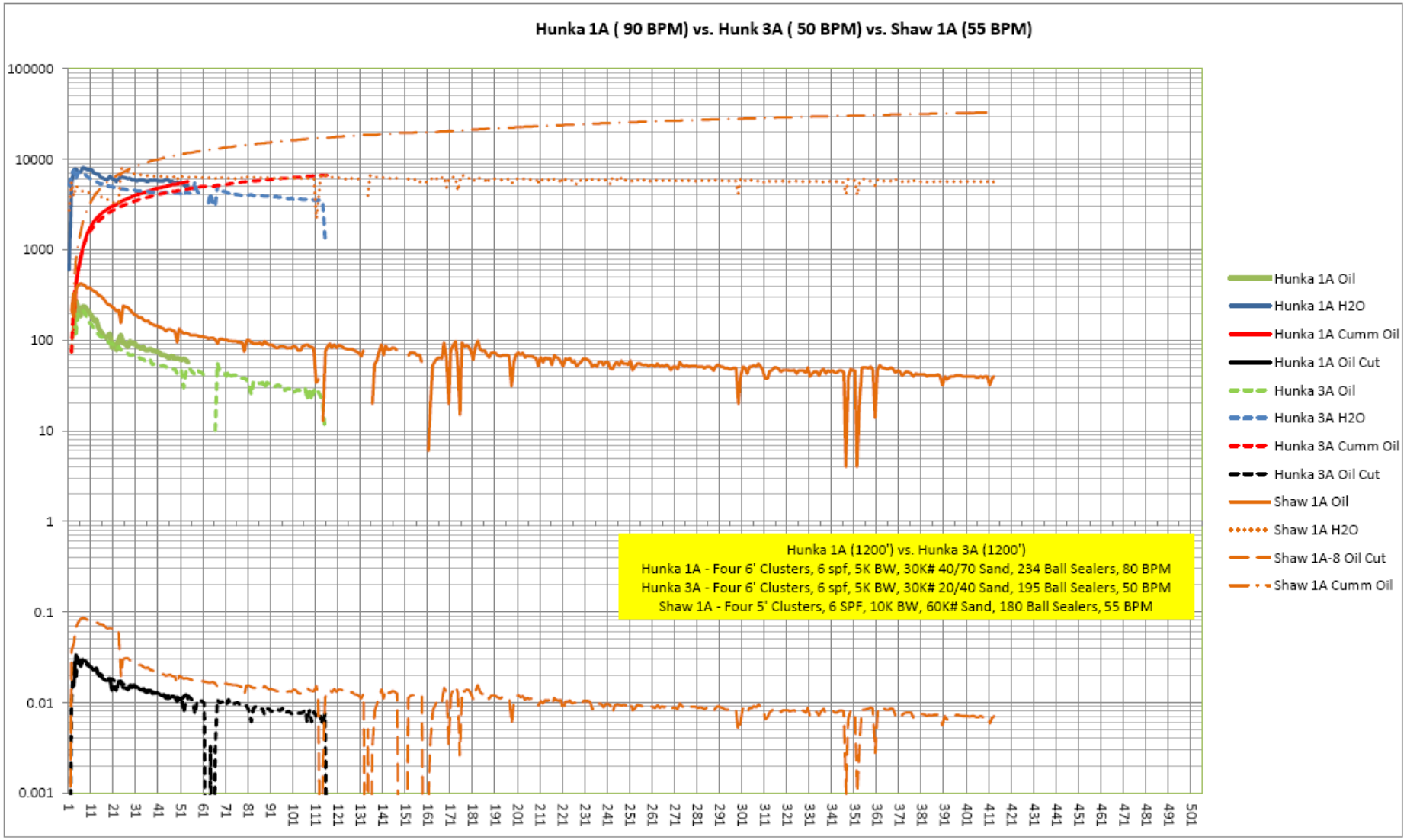
Unconventional Stimulation

- 400’ Stage
- Four 5-Foot Perf Clusters
- Six Shots Per Foot
- 120 Shots per stage
- 5000 to 10,000 BW
- 30K # to 60K # Sand (0.10 # per gal max)
- 160 Bio-Ball Sealers dropped in sub-stages
  - Good Ball Action

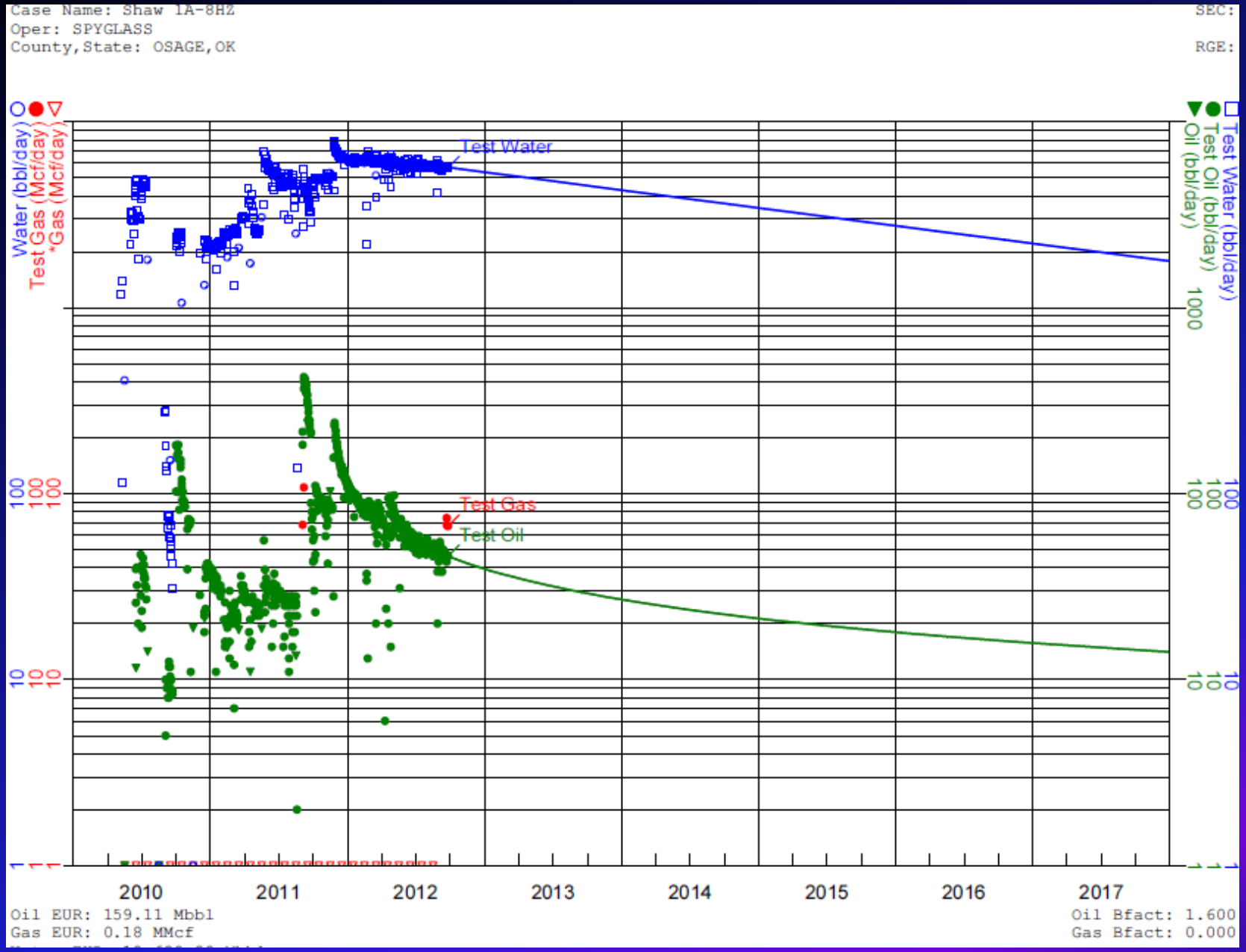
Osage B Unaltered – 50 BPM vs. 80 BPM



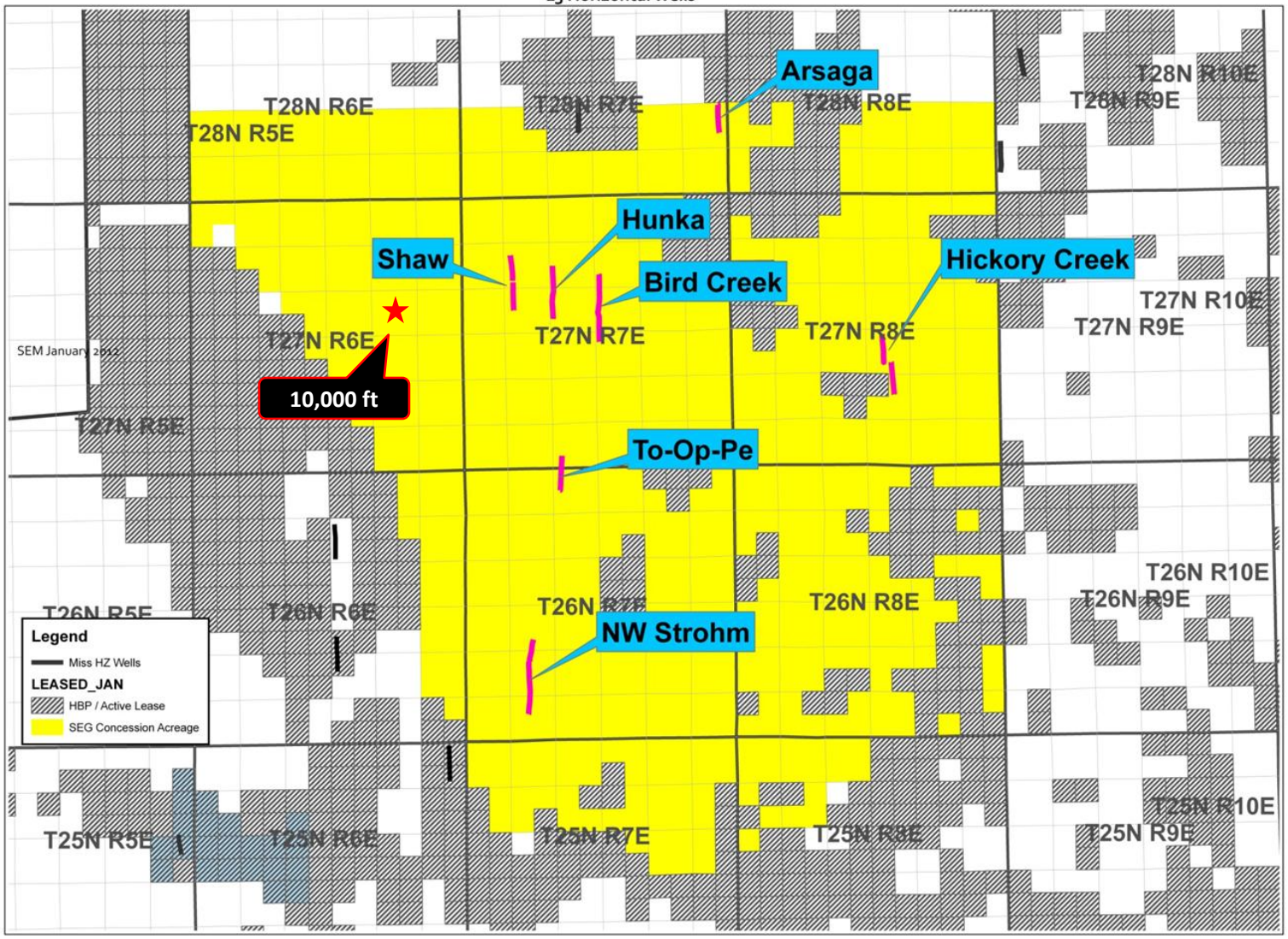
Osage B – Unaltered – 5K BW vs. 10K BW

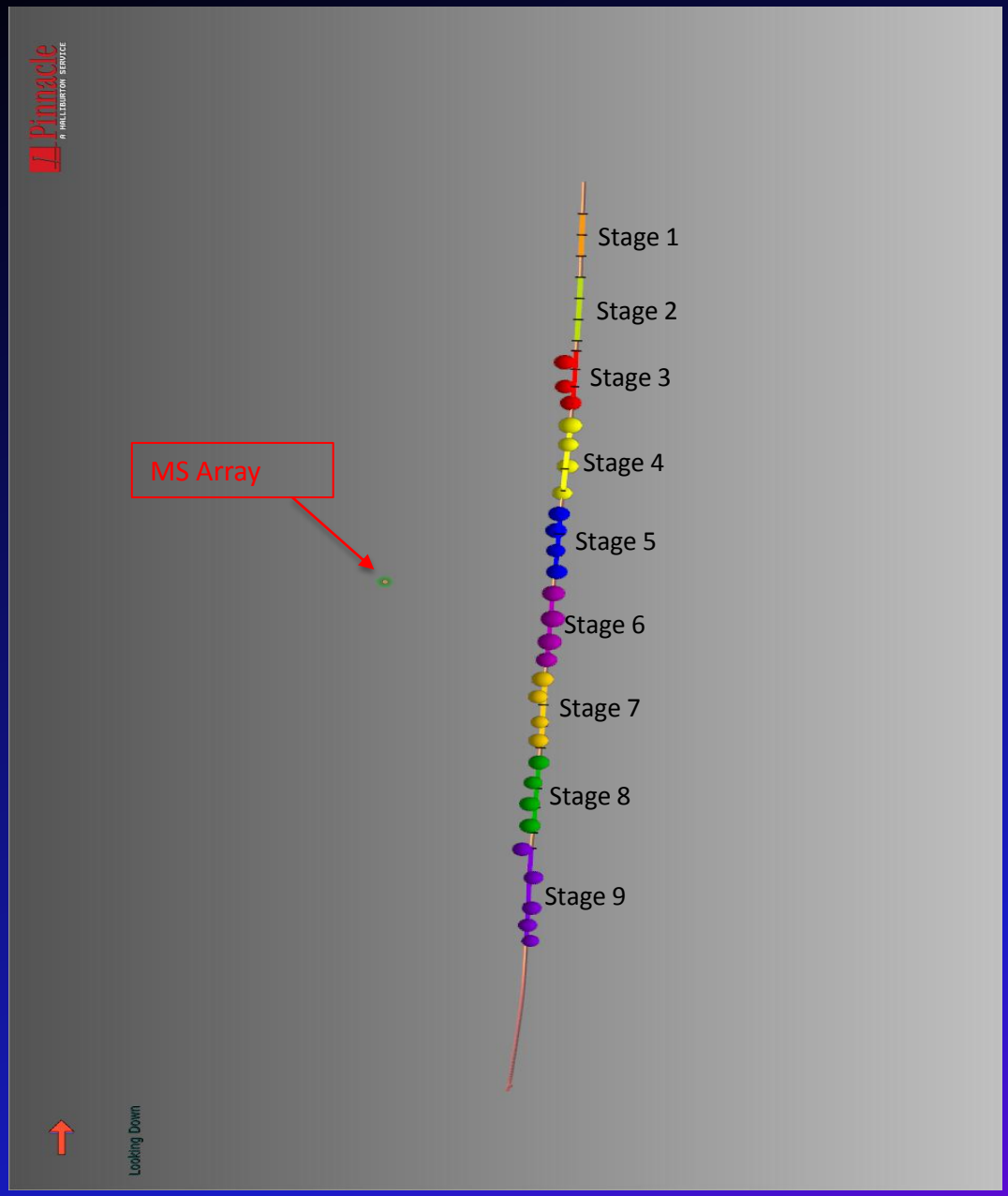


EUR 159,000 BO – 1200’ Lateral



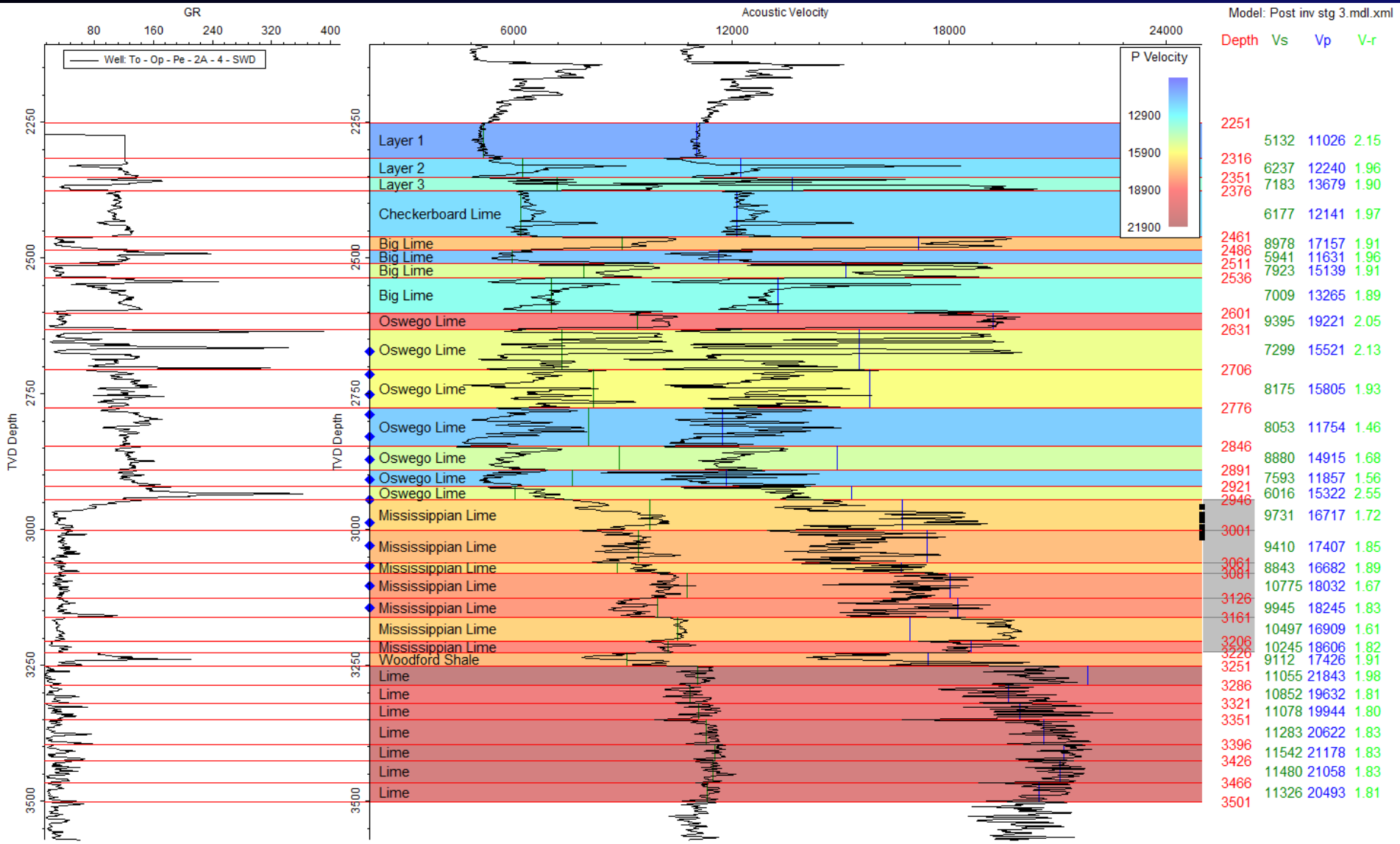
Pearsonia West Concession 2012
Osage Mineral Estate
123,000 net acres - 100% WI
13 Horizontal Wells





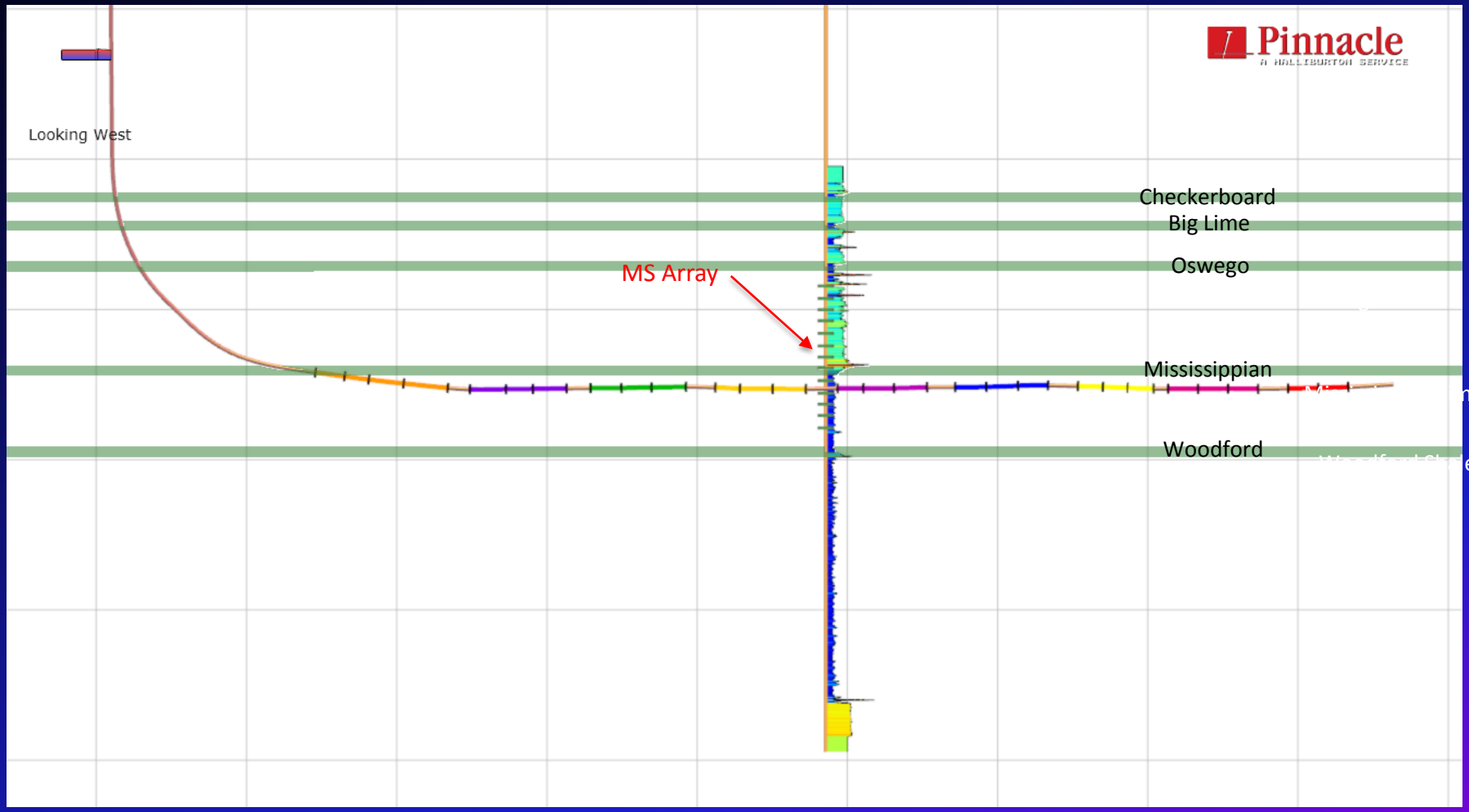
To-Op-Pe 1A-4H
Stage Map
9 Stage
400’ Interval

To-Op-Pe 1A-4H – Velocity Model

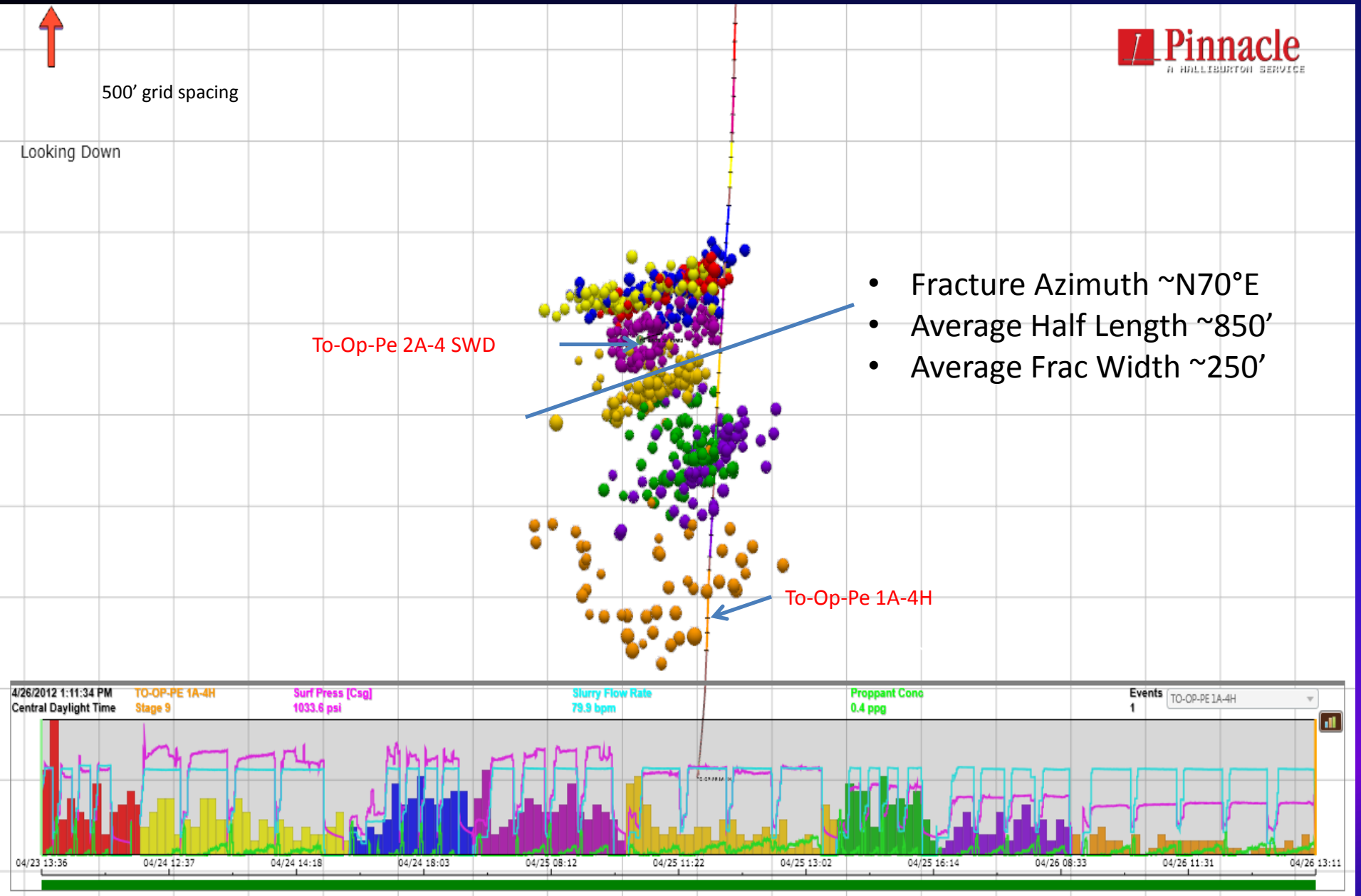


Initial velocity model was constructed from client provided gamma-ray and dipole sonic. The model was further refined with perf-timing measurements and error reducing optimizations on the perforation locations.

To-Op-Pe 1A-4H – Project Setup - Side View

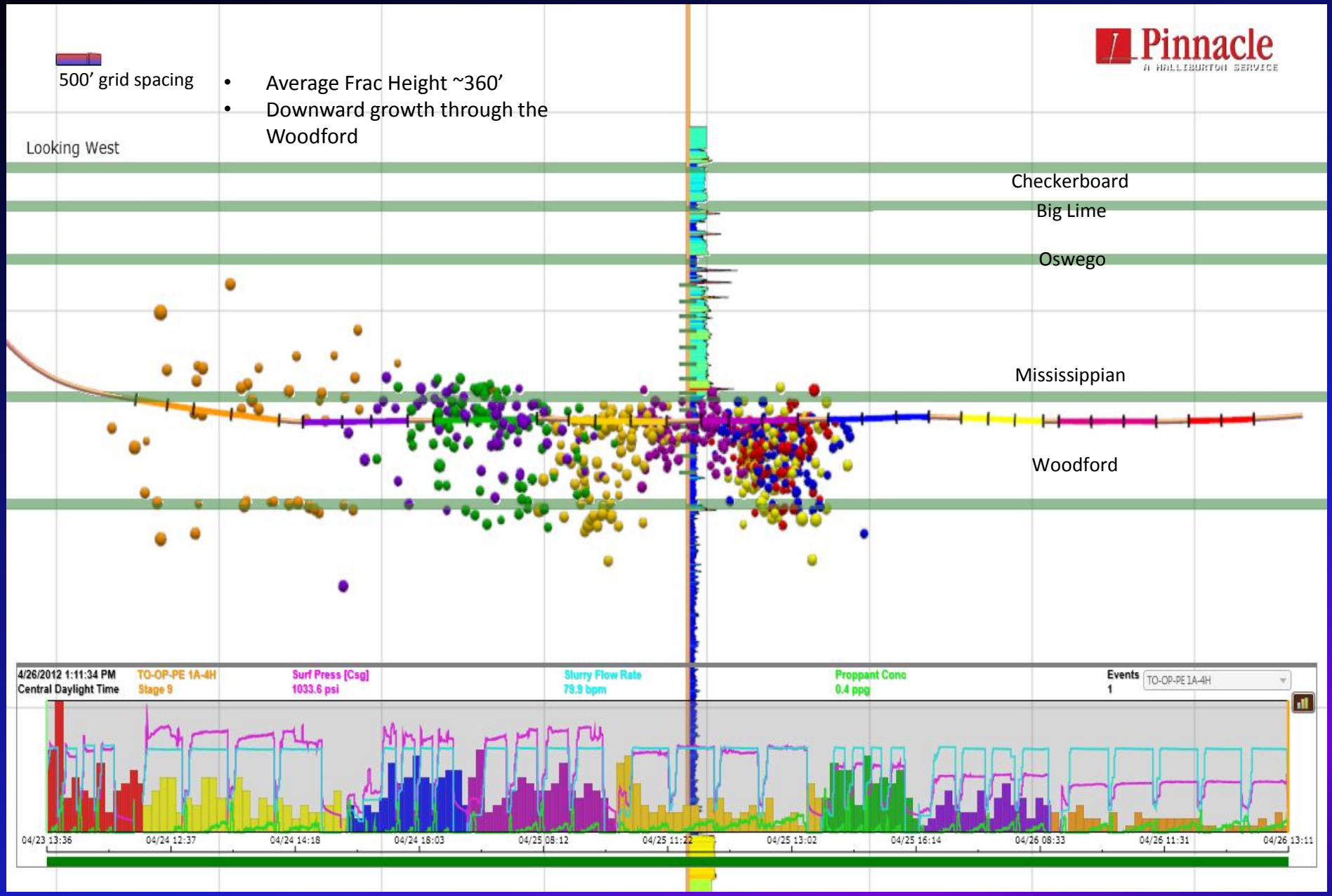


To-Op-Pe 1A-4H – Plan View



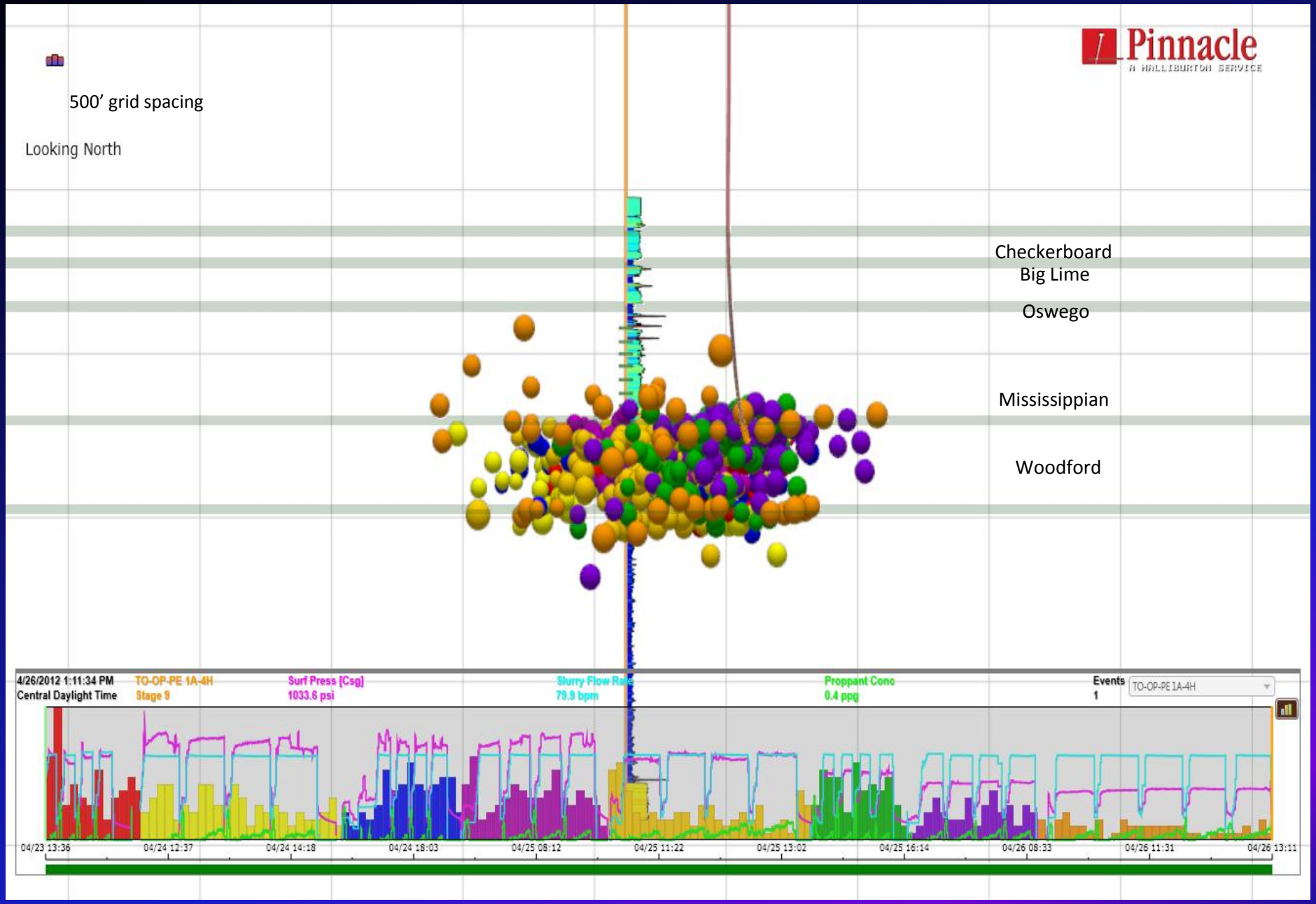
- Fracture Azimuth ~N70°E
- Average Half Length ~850'
- Average Frac Width ~250'

To-Op-Pe 1A-4H – Side View

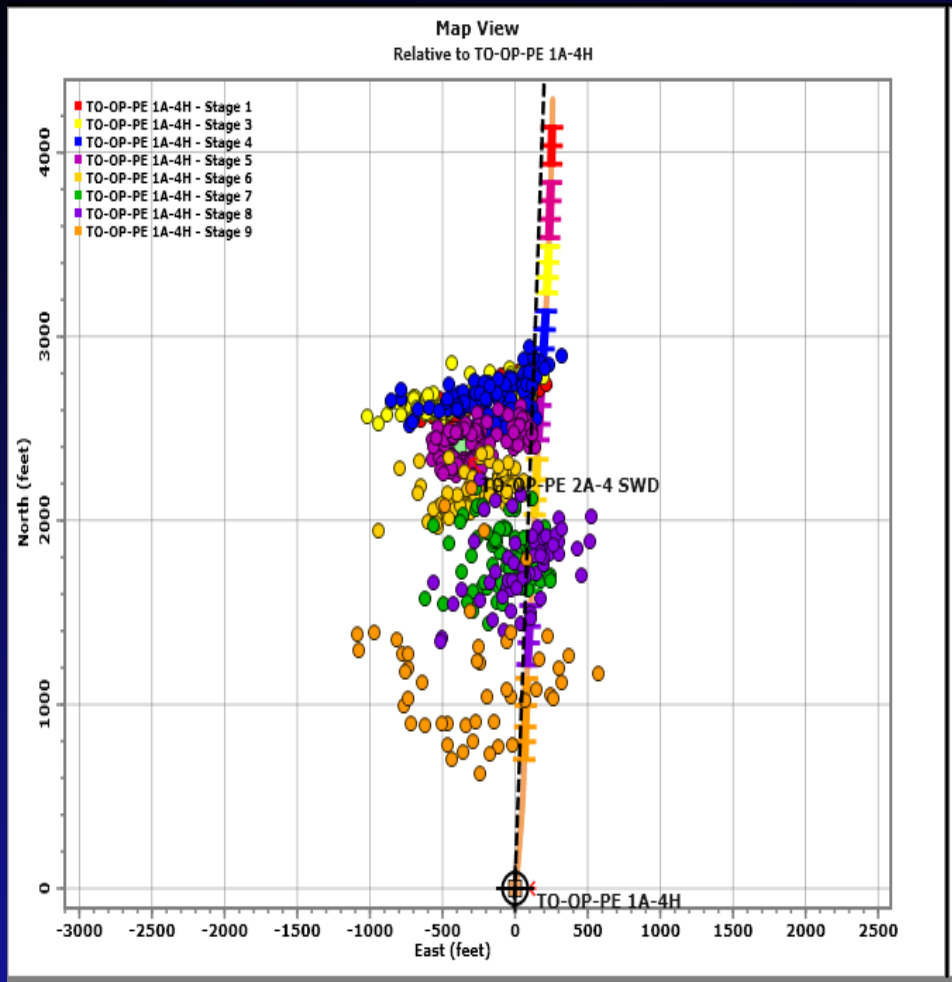


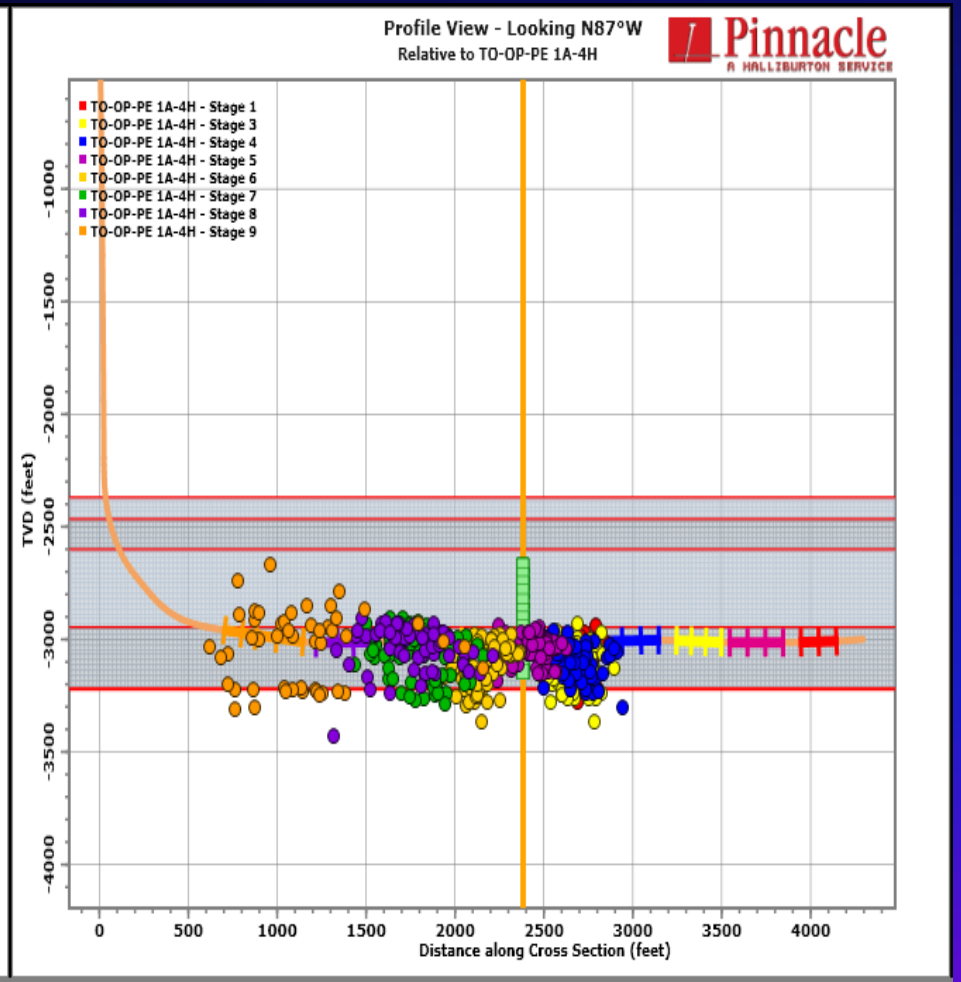
- Average Frac Height ~360'
- Downward growth through the Woodford

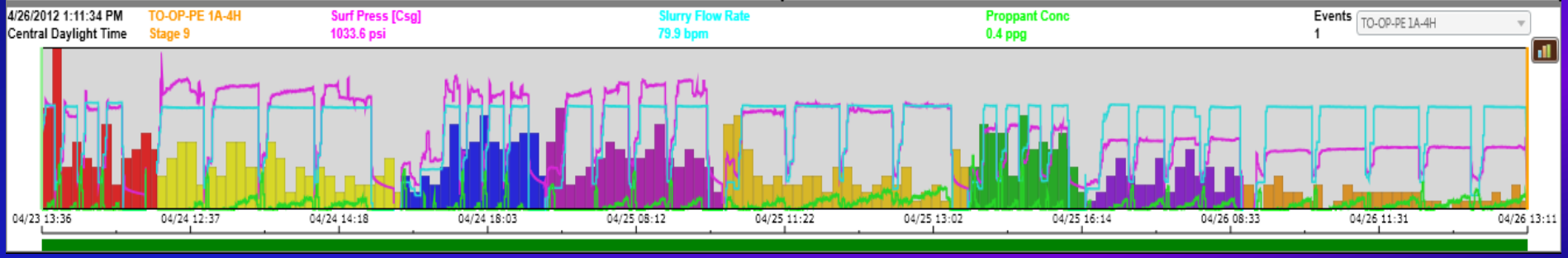
To-Op-Pe 1A-4H – Edge View



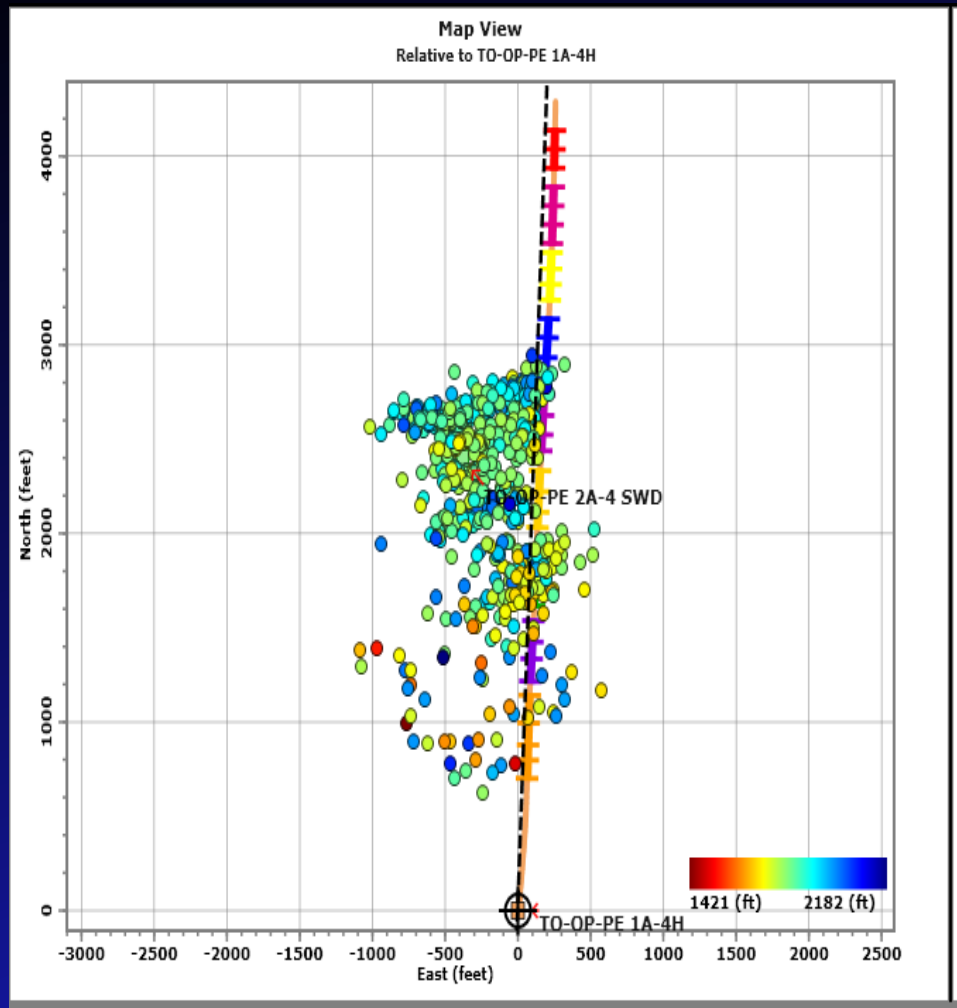
To-Op-Pe 1A-4H – 2D Stage View

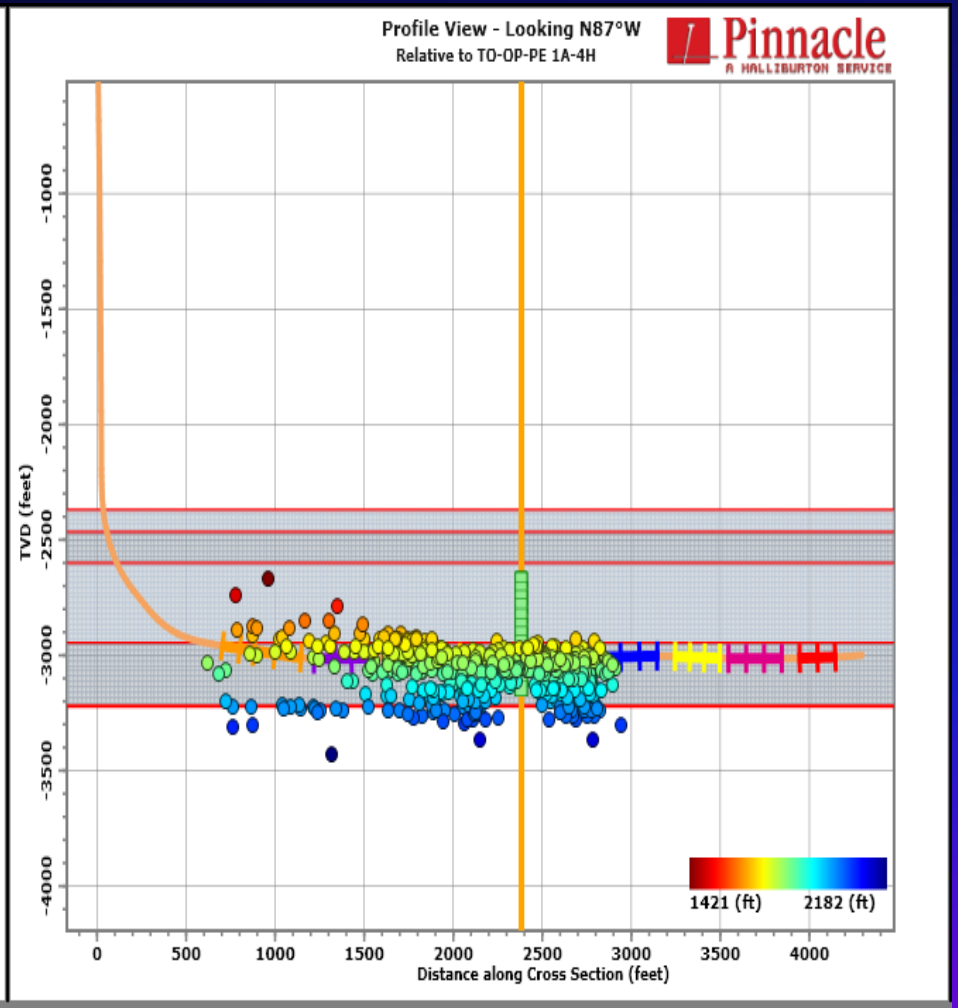


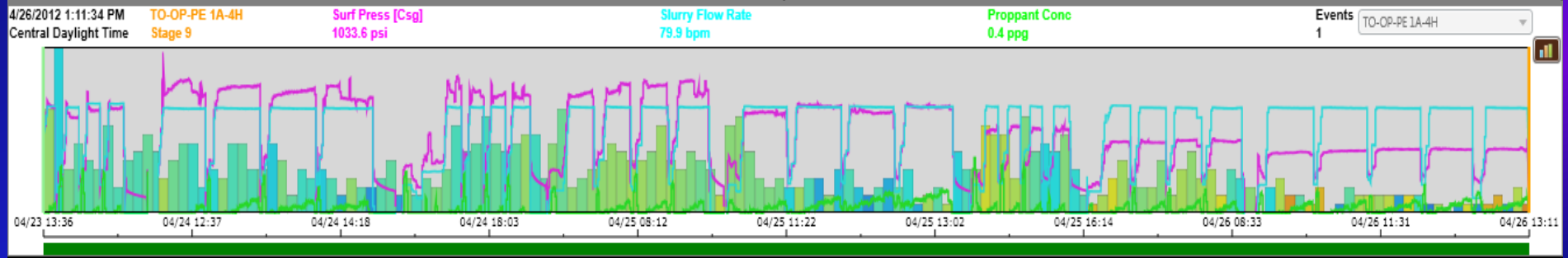




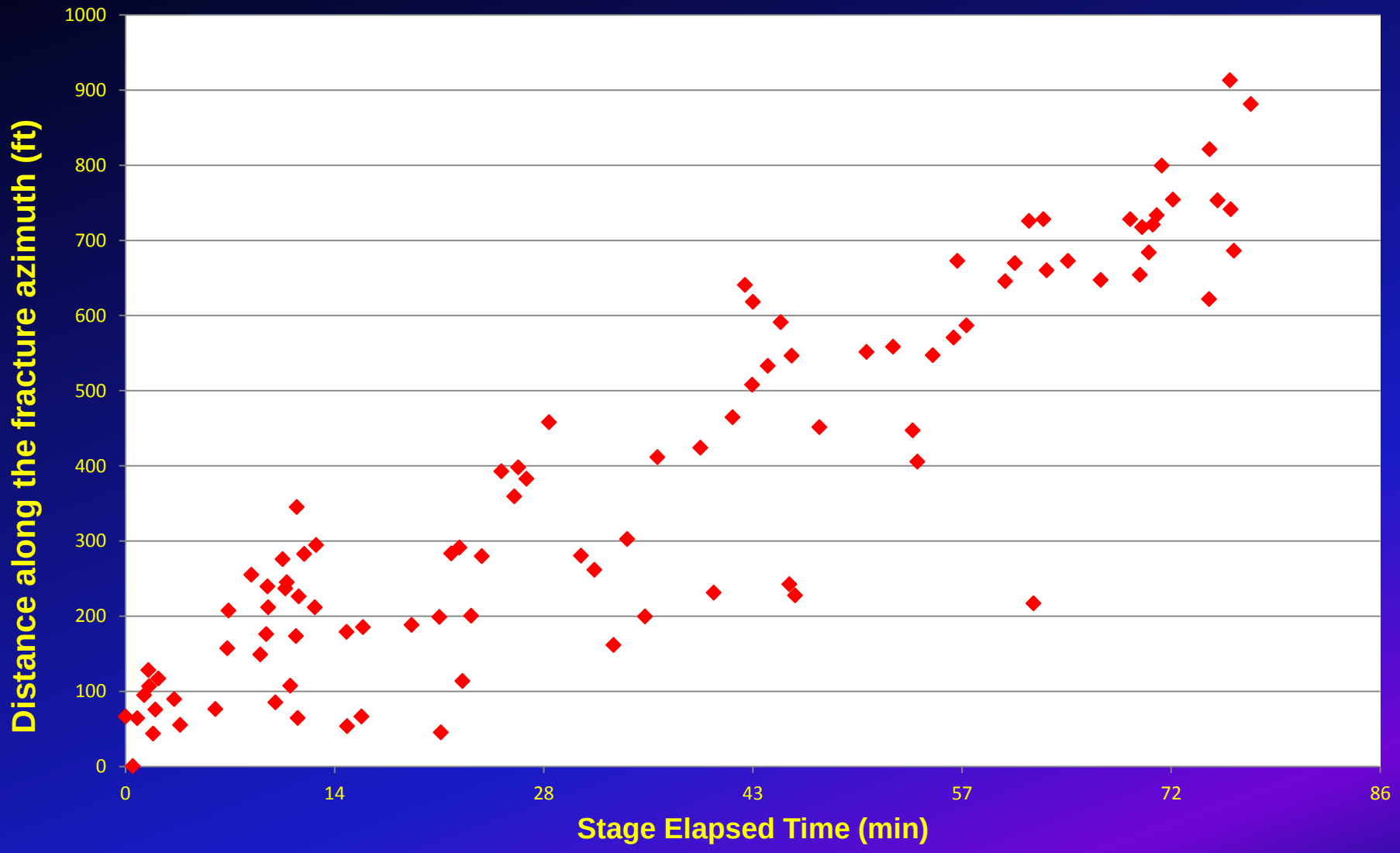
To-Op-Pe 1A-4H – 2D Depth View



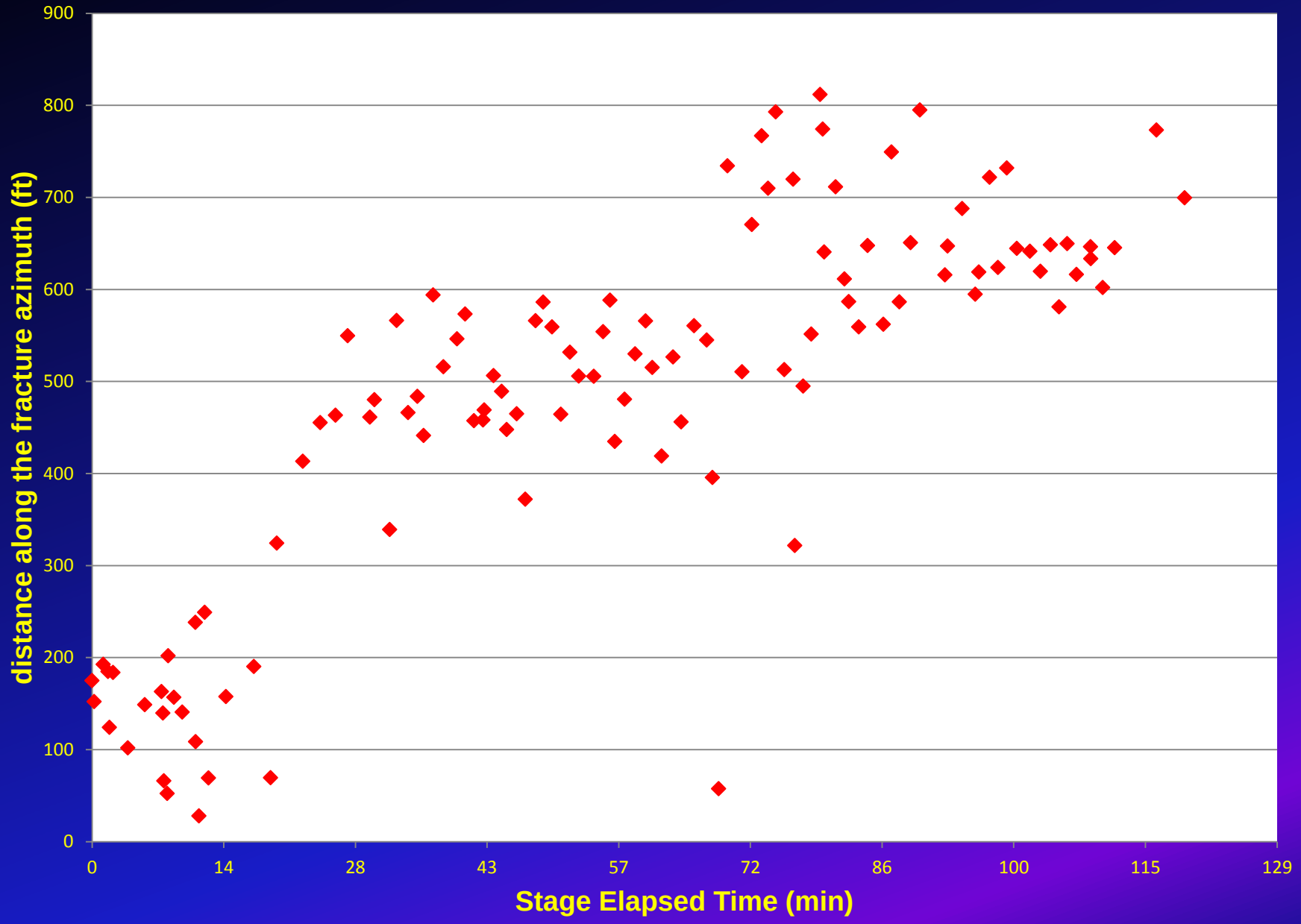




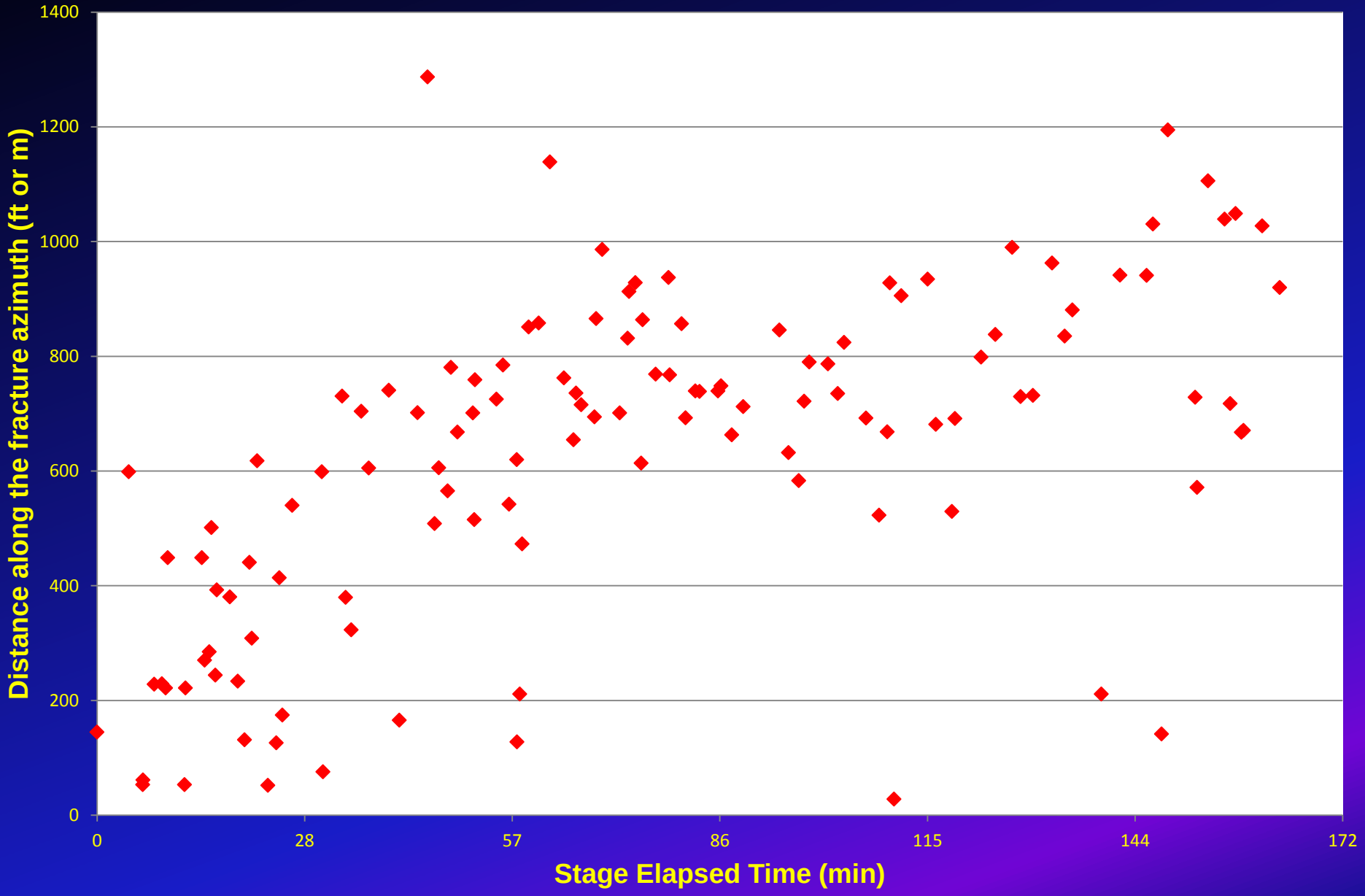
Stage 1
Half Length vs Time
81 BPM Average, 3620 BBL Slickwater

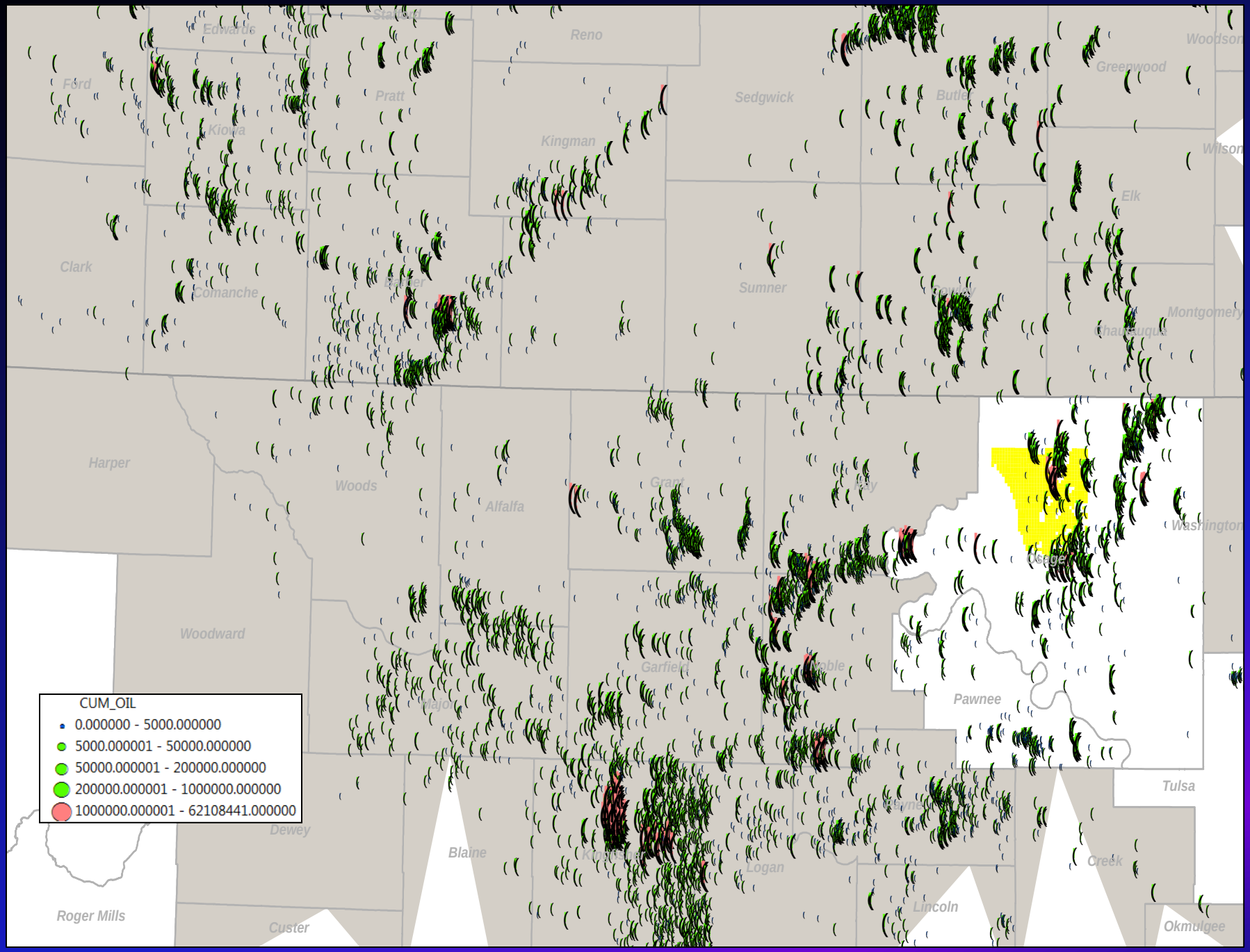


Stage 5
Half Length vs Time
80 BPM Average, 6760 BBL Slickwater



Stage 3
Half Length vs Time
80 BPM Average, 10849 BBL Slickwater




Edwards
Stafford
Reno
Woodson
Greenwood
Ford
Pratt
Sedgwick
Butler
Kiowa
Kingman
Wilson
Elk
Clark
Comanche
Barber
Sumner
Cowley
Montgomery
Chautauqua
Harper
Woods
Grant
Kay
Alfalfa
Washington
Osage
Woodward
Garfield
Noble
Major
Pawnee
Tulsa
Dewey
Blaine
Kingfisher
Logan
Creek
Lincoln
Roger Mills
Custer
Okmulgee
CUM_OIL
0.000000 - 5000.000000
5000.000001 - 50000.000000
50000.000001 - 200000.000000
200000.000001 - 1000000.000000
1000000.000001 - 62108441.000000

Conclusions

- This play is about water
  - high-fluid-volume play
- Variable reservoir requires thoughtful stimulation design
  - Understand the rock you are stimulating
- Standing on the shoulders of giants
  - Many of the answers being sought were asked and answered last century

Acknowledgements

- Charles Wickstrom – Spyglass Energy Group
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- Nadel and Gussman
  - Jim Adelson
  - Steve Heyman
  - Dennis Webb
  - Wayne Porter
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- Sal Mazzulo
- Ralph Davis
- Walt Manger
- Doy Zachry